Grayling II Information Base For Generation of Synthetic Thermal Infrared Scenes

Jerrell R. Ballard, Jr.

U.S. Army Engineer Waterways Experiment Station
Vicksburg, MS

SWOE Report 94-8
November 1994

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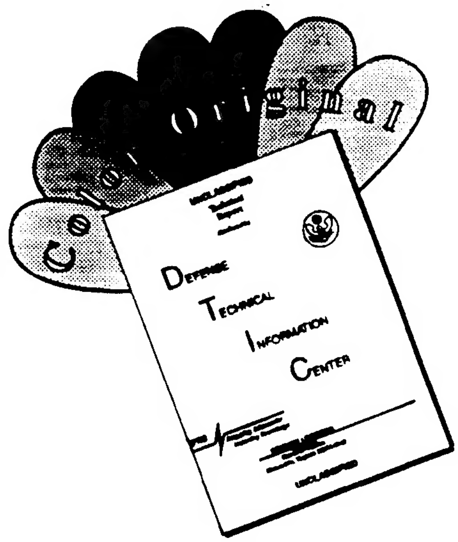

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FOREWORD

SWOE Report 94-8, November 1994, was prepared by J.R. Ballard, Jr. of U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

This report is a contribution to the Smart Weapons Operability Enhancement (SWOE) Program. SWOE is a coordinated, Army, Navy, Marine Corps and Air Force program initiated to enhance performance of future smart weapon systems.

Performance of smart weapons can vary widely, depending on the environment in which the systems operate. Temporal and spatial dynamics can significantly impact weapon performance. Testing of developmental weapon systems has been limited to a few selected combinations of targets and environmental conditions, primarily because of the high costs of full-scale field tests and limited access to the areas or events for which performance data are required.

Performance predictions are needed for a broad range of possible battlefield environmental conditions and targets. Meeting this need takes advantage of significant DoD investments by Army, Navy, Marine Corps, Air Force and ARPA in 1) basic and applied environmental research, data collection, analysis, modeling and rendering capabilities, 2) extensive target measurement capabilities and geometry models, and 3) currently available computational capabilities.

SWOE is developing, validating, and demonstrating the capability to handle complex target and background environment interactions for a broad range of battlefield conditions. SWOE is providing the DoD smart weapons and autonomous target recognition (ATR) communities with measurements, information bases, modeling and scene rendering techniques for complex environments. These are products of a DoD-wide partnership that works in concert with both advanced weapon system developers and major weapon system test and evaluation programs.

The SWOE program started in FY89 under Balanced Technology Initiative (BTI) sponsorship. Present sponsorship is by the U.S. Army Corps of Engineers (lead service), the individual services, and the Joint Test and Evaluation (JT&E) program of the Office of the Director of Test & Evaluation, Office of the Under Secretary of Defense OUSD(A/DT&E).

The Joint Test Director is Dr. J.P. Welsh. The Deputy Test Directors are: COL Jerre Wilson (U.S. Army) and Maj Richard Jennings (U.S. Air Force). The Modeling Configuration Manager is Dr. George G. Koenig.

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13. ABSTRACT *(Maximum 200 words)*

Procedures are being developed for the environmental information base component of the Smart Weapons Operability Enhancement/Joint Test and Evaluation Program analytical thermal infrared scene generation procedure at Camp Grayling, MI. Scope is limited to documentation of the information base content and data processing/analysis procedures developed to satisfy other component requirements such as thermal signature modeling, thermal radiance field predictions, and generation of realistic graphic representations of the three-dimensional thermal backgrounds.

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Preface

The study reported herein was conducted during the period October 1992 to April 1994 by the personnel of the Natural Resources Division (NRD), Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES). The study was authorized by Dr. J. Pat Welsh, Joint Test Director, Smart Weapons Operability Enhancement (SWOE) Joint Test and Evaluation Program (JT&E), Hanover, NH. LTC Jerre W. Wilson was the Army Deputy Test Director, and MAJ Richard Jennings was the Air Force Deputy Test Director.

WES has prepared three related reports in support of the Grayling II exercise for the SWOE/JT&E program. These are as follows:

a. "Grayling II Information Base for Generation of Synthetic Thermal Scenes"

b. "Grayling II Site Characterization and Data Summary"

c. "Analysis of Thermal Imagery Collected at Grayling II, Grayling, Michigan"

Mr. Jerrell R. Ballard, Jr., Environmental Characterization Branch (ECB), NRD, was Principal Investigator and responsible for development of the static information base and data analysis procedures. Mr. John Manby and Mr. Eddie Melton contributed to data analysis. Mr. Ballard prepared the report.

The work was conducted under the general supervision of Mr. Harold W. West, Chief, ECB; Dr. Robert M. Engler, Chief, NRD; and Dr. John W. Keeley, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or kelvins[1]
feet	0.3048	meters
inches	2.54	centimeters

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain kelvin (K) readings, use the following formula: K = (5/9)(F - 32) + 273.15.

1 Introduction

Background

The Smart Weapons Operability Enhancement/Joint Test and Evaluation (SWOE/JT&E) Program is a multiservice (U.S. Army, Navy, and Air Force) initiative designed to enhance smart weapons systems performance by providing the technology to simulate complex environmental backgrounds in a broad range of battlefield conditions. The smart weapons being designed to locate and acquire targets automatically must be able to isolate targets in complex and varied environmental scenes. The technology and data provided by the SWOE/JT&E program will enhance the ability to characterize the effects of various terrain and atmospheric conditions on smart weapons sensor performance. SWOE conducted a Grayling I imaging and data collection exercise during the period from 15 September to 25 October 1992 and a Grayling II exercise during the period 4 March to 15 April 1994. Data resulting from these field exercises were then used for validation of the SWOE/JT&E thermal scene generation procedure and to provide an imagery and terrain database for future use by the smart weapons' development, test, and evaluation (DT&E) community.

Purpose

This report details the design, content, and development of the Grayling II information base. This information base provides spatial and tabular terrain and atmospheric data required by the various models within the SWOE/JT&E thermal scene generation procedure. The actual computer-compatible data formats required for the SWOE/JT&E scene procedure are described in Appendix A.

Location and Size of Information Base Area

An area at Camp Grayling, MI (Figure 1), was selected for the development of the information base component of the SWOE/JT&E end-to-end scene generation procedure. The area selected is illustrated in Figure 2. The landscape area considered is approximately 1.42 by 1.22 km with local relief of about 29 m. All geographic data were projected into the universal transverse Mercator (UTM) projection in zone 16 and referenced to the North American Datum 1983 (NAD83). The U.S. Army Engineer Waterways Experiment Station (WES) prepared an information base for Grayling I and is described in Ballard (1994). The Grayling II information base is an enhanced information base (Release 4.0) generated using the Grayling I information base (Release 2.0) and is based on additional site characterization and meteorological data. This 4 March to 15 April 1994 time period represented the winter-to-spring site conditions including both snow, frozen ground conditions, and melting snow/standing water type surface conditions.

2 Information Base Design and Compilation

Content and Structure

The function of the Grayling II digital information base is to provide spatial, thermal property, and spatial attribute data required by the thermal models in the SWOE scene generation procedure. The design also includes the concept of machine-independent digital data formats that allow maximum portability between different computer architectures. Guidance for the design and implementation of the Grayling II information base is detailed in Kress (1992).

Releases

During the SWOE/JT&E program, release numbers were established and assigned to all information base products. The release number convention allowed the continual updating and enhancement of the Grayling information base resulting from characterization data collected prior to and during each field exercise and ongoing improvements to the various models used within the SWOE scene generation procedure. During the SWOE program, four releases were developed for the Grayling site. Releases 1.0 and 3.0 were preliminary releases for Grayling I and Grayling II information bases, respectively. The Grayling II information base, Release 4.0, is an enhanced version of the Grayling I information base, Release 2.0. The enhancements made to Release 2.0 to produce Release 4.0 are described in this report.

Data Sources

Data used for the development of the Grayling information base was obtained from two sources: aerial photo stereo pairs and WES site characterization measurements, as briefly described below.

Aerial photo stereo pairs

Aerial photo stereo pairs (1:12,000 scale), were obtained from Midwest Aerial Photography in Columbus, OH, and were used to generate initial vegetation and elevation data for the Camp Grayling area. Data were interpreted/prepared by the U.S. Army Engineer Topographic Engineering Center (TEC) Fort Belvoir, VA, using the Terrain Information Extraction System (TIES).

Site characterization measurements

Various types of quantitative data were collected by WES during the periods of October 1992, October 1993, and April 1994 to characterize the physical, geometric, and geographic characteristics of the vegetation, topography, soils, and roads that occurred in the area. A complete discussion of these characterization measurements and collection techniques used by WES are described in SWOE reports Hahn (1994) and Hahn and Berry (1994).

Data Development and Presentation

The Grayling II information base (Release 4.0) contains four different types of digital data: terrain data (e.g., topography, vegetation type cover, snow cover, and soil types); meteorological data (e.g., air temperature, barometric pressure, wind speed, and direct and diffuse solar radiation); three-dimensional tree data (e.g., tree basal location and geometric tree models); and texture data. The description of the digital formats is provided in Appendix A. Enhancements made to each of the terrain parameters are discussed below.

Topographic elevation data

Elevation data were developed using photography and field measurements and provided for the Grayling I information base (Release 2.0). Data were generated at 1-m grid post spacing using ARC-INFO software as required for all terrain data components. From Release 2.0 to Release 4.0, no changes were made in the elevation component. A description of

the development of the elevation data for the Grayling site is described in Ballard (1994).

Provided in Figure 3 is a graphic showing the elevation characteristics of the Grayling site. The colors range from dark brown to a light yellow and correspond to changes in topographic elevation from low (251.8 m) to high (378.1 m). The dark gray colors indicate the presence of a small valley in the Grayling area that runs the length of the area from the southwest to northeast. Elevation contour data (lines), spaced at 2-m intervals, were generated using the Environmental Systems Research Institute (ESRI) ARC-INFO system software to illustrate the changes in the topographic elevation.

Slope magnitude data

Slope magnitude data were calculated using the ARC-INFO software and the 1-m elevation data discussed above. Slope data were then classed into five degree classes (Table 1). Thermal model sensitivity in the SWOE scene generation procedure made it necessary to reduce the spatial variability of the slope magnitude and slope aspect data into a limited number of classes. No changes were made in the slope data layer between Release 2.0 and Release 4.0. A description of the development of the slope component is described in Ballard (1994).

Table 1
Class Ranges for Slope

Class	Class Range, deg	Slope Value Used for Calculation	Area Covered, percent
1	0 to 5	3.0	72.7
2	>5 to 10	8.0	21.8
3	>10 to 15	13.0	4.2
4	>15 to 20	18.0	1.0
5	>20	23.0	0.3

Provided in Figure 4 is a graphic depiction of the slope magnitude data using the five selected classes. The five colors correspond to the slope classes shown in Table 1. In the valley region and the primary SWOE imaging area (Site E), the slope was less than 5 deg (class 1). On the sides of the natural hills and man-made berms that occurred in the valley area, the slopes were greater than 10 deg. It is noteworthy that 73 percent of the 1.42- by 1.22-km Grayling area is within the 0- to 5-deg class and 94.5 percent of the total area has slopes less than 10 deg (classes 1 and 2).

Slope aspect data

The slope aspect data were calculated using the ARC-INFO software and then classed into four 90-deg classes. From Release 2.0 to Release 4.0, no changes were made in the slope aspect component. A description of the development of the slope aspect component is described in Ballard (1994).

Provided in Figure 5 is a graphic showing the classed slope aspect data. The four colors correspond to the slope aspect classes shown in Table 2. The green regions (class range >90 to 180 deg) are southeast-facing slopes and therefore ones that receive most of the incident solar loading during the morning hours, while the red regions (class range >181 to 270 deg) receive most of the incident solar loading during the afternoon daylight hours. The classed aspect data show 32 percent of the area in class 2 and 31 percent in class 4, thereby indicating approximately 63 percent of the slopes are oriented along a southeast to northwest direction.

Table 2
Class Ranges for Slope Aspect

Class	Class Range, deg	Slope Value Used for Calculation	Area Covered, percent
1	1 to 90	45	13.9
2	91 to 180	135	32.0
3	181 to 270	225	22.9
4	271 to 360	315	31.2

Surface and subsurface soil type data

The surface and subsurface soil data were developed with descriptions compatible with current SWOE thermal model capabilities. From Release 2.0 to Release 4.0, no changes were made in the surface and subsurface soils data layer. A description of the development of the soils component is described in Ballard (1994).

Vegetation type data

The vegetation type data were developed at a 1-m grid post spacing with descriptions of the vegetation compatible with current SWOE thermal model capabilities. No changes were made in the vegetation type cover data between Releases 2.0 and 4.0. A description of the development of the vegetation type component is described in Ballard (1994). Although the vegetation type did not change, thermal characteristics of the vegetation

did change dramatically because of the winter conditions that occurred prior to and during the Grayling II period (4 March - 15 April 1994). Data on these parameters are provided in Appendix B.

Provided in Figure 6 is a graphic depiction of the vegetation type data. The five colors correspond to the vegetation classes shown in Table 3. The light green class (grass vegetation) shows that approximately 53 percent of the area is covered by medium density grass. The forested areas (classes 3, 4, and 5) cover approximately 36 percent of the landscape area. The bare (nonvegetated) class covers approximately 10 percent of the area.

Table 3
Vegetation Class Types

Class	Vegetation Type	Description	Area Covered, percent
1	BARE (nonvegetated)	Bare ground, exposed surface soil	10.6
2	MVEG	Grass vegetation, medium density	52.8
3	DECI	Deciduous forest	1.4
4	CONF	Coniferous forest	14.5
5	MIXF	Mixed (deciduous, coniferous) forest	20.7

Composite data

The composite data were developed by combining 1-m data on elevation, slope magnitude, slope aspect, surface soil, subsurface soil, and vegetation type. This composite data layer resulted in 100 unique landscape units. A complete listing of the 100 landscape features in the Grayling area is provided in Table 4. This composite data did not change from Release 2.0 to Release 4.0. A complete description of the development of the composite data component of the 100 landscape features is provided in Ballard (1994). Figure 7 is a graphic depiction of the landscape features within the 1.42- by 1.22-km area. Each unique landscape feature is assigned a color and illustrates the complexity of the Grayling area. The largest landscape unit covered 14 percent of the area and consisted of medium density grass, with less than 5-percent slope magnitude, a southeast-facing slope, and was composed of a sandy surface and subsurface soil material.

Meteorological data

Meteorological data were collected by the U.S. Army Research Laboratory (ARL) and the U.S. Army Engineer Cold Regions Research and Engineering Laboratory (CRREL) (see SWOE Field Test Plan, January 1994) in real time using several field stations during the Grayling II field exercise

Table 4
Landscape Feature Codes and Descriptions Present in Grayling II Information Base

Landscape Feature Code	Vegetation Type	Surface Soil	Subsurface Soil	Ground Slope Value	Slope Aspect Value
001	BARE	SAND	SAND	03	045
002	BARE	SAND	SAND	03	135
003	BARE	SAND	SAND	03	225
004	BARE	SAND	SAND	03	315
005	BARE	SAND	SAND	08	045
006	BARE	SAND	SAND	08	135
007	BARE	SAND	SAND	08	225
008	BARE	SAND	SAND	08	315
009	BARE	SAND	SAND	13	045
010	BARE	SAND	SAND	13	135
011	BARE	SAND	SAND	13	225
012	BARE	SAND	SAND	13	315
013	BARE	SAND	SAND	18	045
014	BARE	SAND	SAND	18	135
015	BARE	SAND	SAND	18	225
016	BARE	SAND	SAND	18	315
017	BARE	SAND	SAND	23	045
018	BARE	SAND	SAND	23	135
019	BARE	SAND	SAND	23	225
020	BARE	SAND	SAND	23	315
021	MVEG	SAND	SAND	03	045
022	MVEG	SAND	SAND	03	135
023	MVEG	SAND	SAND	03	225
024	MVEG	SAND	SAND	03	315
025	MVEG	SAND	SAND	08	045
026	MVEG	SAND	SAND	08	135
027	MVEG	SAND	SAND	08	225
028	MVEG	SAND	SAND	08	315
029	MVEG	SAND	SAND	13	045
030	MVEG	SAND	SAND	13	135
031	MVEG	SAND	SAND	13	225
032	MVEG	SAND	SAND	13	315
033	MVEG	SAND	SAND	18	045
034	MVEG	SAND	SAND	18	135
035	MVEG	SAND	SAND	18	225
036	MVEG	SAND	SAND	18	315
037	MVEG	SAND	SAND	23	045
038	MVEG	SAND	SAND	23	135
039	MVEG	SAND	SAND	23	225
040	MVEG	SAND	SAND	23	315
041	DECI	SAND	SAND	03	045
042	DECI	SAND	SAND	03	135
043	DECI	SAND	SAND	03	225
044	DECI	SAND	SAND	03	315
045	DECI	SAND	SAND	08	045
046	DECI	SAND	SAND	08	135
047	DECI	SAND	SAND	08	225
048	DECI	SAND	SAND	08	315
049	DECI	SAND	SAND	13	045
050	DECI	SAND	SAND	13	135
051	DECI	SAND	SAND	13	225
052	DECI	SAND	SAND	13	315
053	DECI	SAND	SAND	18	045
054	DECI	SAND	SAND	18	135
055	DECI	SAND	SAND	18	225
056	DECI	SAND	SAND	18	315
057	DECI	SAND	SAND	23	045
058	DECI	SAND	SAND	23	135

(Continued)

Table 4 (Concluded)

Landscape Feature Code	Vegetation Type	Surface Soil	Subsurface Soil	Ground Slope Value	Slope Aspect Value
059	DECI	SAND	SAND	23	225
060	DECI	SAND	SAND	23	315
061	CONF	SAND	SAND	03	045
062	CONF	SAND	SAND	03	135
063	CONF	SAND	SAND	03	225
064	CONF	SAND	SAND	03	315
065	CONF	SAND	SAND	08	045
066	CONF	SAND	SAND	08	135
067	CONF	SAND	SAND	08	225
068	CONF	SAND	SAND	08	315
069	CONF	SAND	SAND	13	045
070	CONF	SAND	SAND	13	135
071	CONF	SAND	SAND	13	225
072	CONF	SAND	SAND	13	315
073	CONF	SAND	SAND	18	045
074	CONF	SAND	SAND	18	135
075	CONF	SAND	SAND	18	225
076	CONF	SAND	SAND	18	315
077	CONF	SAND	SAND	23	045
078	CONF	SAND	SAND	23	135
079	CONF	SAND	SAND	23	225
080	CONF	SAND	SAND	23	315
081	MIXF	SAND	SAND	03	045
082	MIXF	SAND	SAND	03	135
083	MIXF	SAND	SAND	03	225
084	MIXF	SAND	SAND	03	315
085	MIXF	SAND	SAND	08	045
086	MIXF	SAND	SAND	08	135
087	MIXF	SAND	SAND	08	225
088	MIXF	SAND	SAND	08	315
089	MIXF	SAND	SAND	13	045
090	MIXF	SAND	SAND	13	135
091	MIXF	SAND	SAND	13	225
092	MIXF	SAND	SAND	13	315
093	MIXF	SAND	SAND	18	045
094	MIXF	SAND	SAND	18	135
095	MIXF	SAND	SAND	18	225
096	MIXF	SAND	SAND	18	315
097	MIXF	SAND	SAND	23	045
098	MIXF	SAND	SAND	23	135
099	MIXF	SAND	SAND	23	225
100	MIXF	SAND	SAND	23	315

(4 March to 15 April 1994) and provided to the onsite SWOE modeling team on a daily basis. Parameters include air temperature, relative humidity, wind speed, wind direction, visibility, precipitation, cloud type, and solar direct diffuse radiation. A detailed description of these meteorological parameters, collection, and processing is provided in Hahn (1994).

Texture data

Texture data were developed for the Grayling II information base (Release 4.0) using measured imagery data; emphasis was placed on generating texture data for snow. Texture data were then calculated on correlation length and standard deviation for both 3- to 5- and 8- to 12-µm wave bands.

The texture data were collected, processed, and provided to the SWOE modeling team on a by mission basis. A complete description of the procedures used for the generation of the texture data is provided in Sabol (1994) (See Annex C: Models Package section entitled Texturing Procedures).

Snow cover data

Snow cover data were collected by WES and ARL for each daytime mission during the Grayling II exercise, and a snow cover map (and data file) was produced. The time period of the exercise represented the winter-to-spring conditions that included the presence of snow and/or standing water (resulting from melting snow). These physical changes in the snow cover significantly impact the thermal signatures; therefore, it is important that these changes be modeled (Jordan 1991). The description of the WES data collection efforts related to snow cover mapping is provided in Hahn (1994).

The WES-collected Charge Couple Device (CCD) visual imagery data used for snow cover mapping were imported into the Earth Resources Data Analysis System (ERDAS) imaging processing system, where the data were processed into two classes, snow and no-snow, by using a sequential clustering method. This classed image was then rectified and coregistered to the Grayling information base. Examples of the WES CCD imagery and the resulting snow cover maps for 26 daytime missions are shown in Figures 8 and 9, respectively.

Three-dimensional geometric tree data

Three-dimensional (3-D) geometric tree data consist of representations of dominant vegetation structures in the area such as trees and forest stands. Data include tree types, heights, densities, basal locations, and 3-D stem and branching structures.

The tree basal location data were developed using three different data sources: site characterization survey, 1:12,000 aerial photogrammetric interpretation, and computer analysis. For Release 4.0, data on tree basal locations were developed using a new procedure. A description of this procedure is provided below.

Data collected by WES during the site characterization survey (see Hahn 1994) consisted of tree/plant types, geographic basal locations, and heights and widths of all individual trees and plants within the vicinity of the ground imaging area (Site E) and along the forested edge that paralleled the vehicle test track. These data were processed using the ARC-INFO system and registered with all other geographic data in the information base. Each of these surveyed tree locations were then assigned a representative 3-D geometric tree model based on the measured tree type, height, and width characteristics.

To complement the on-ground site characterization survey, tree locations within the designated forested areas were determined by interpolation of the 1:12,000 aerial photography. This interpolation was achieved by using data on three measured samples that provided the spatial distribution of trees per 100 m^2. The calculated forest density parameters are listed in Table 5. A computer program was written to generate tree locations, type, height, and width using the interpolated densities for the forested areas. These generated tree locations were then digitized directly into the ARC-INFO system as attributed points and coregistered with all other geographic data components in the information base. Each of these digitized tree locations was then assigned a tree type, height, and representative 3-D geometric tree model, based on ground photos and other characterization data obtained during the field survey.

Table 5
Calculated Tree Density Parameters

Sample Number	Oak, trees/100 m^2	Pine, trees/100 m^2
1	5	1
2	1	5
3	8	1

Approximately 5,658 tree basal locations were deemed necessary for depicting the spacing distribution of the various tree types within the Grayling site. A sample listing of the calculated basal positions with the appropriate tree model information is shown in Table 6. Data are provided on longitude, latitude, basal elevation (above-sea-level), and tree modeling information including vertical scale, tree model code, rotation, and horizontal scale. The vertical and horizontal scaling values and their development are described in Ballard (1994). Figure 10 shows the distribution of the 5,658 trees within the Grayling area.

Table 6
Sample Listing of Tree Model Location File

Tree Base Location			Tree Model Data			
Longitude	Latitude	Elevation, m	Vertical Scale	Tree Model ID	Rotation, deg	Horizontal Scale
-84.637822	44.695051	354.33	2.133	o1	90	1.545
-84.637830	44.695045	354.33	2.000	o1	90	1.364
-84.637674	44.695288	355.15	1.846	o2	90	1.636
-84.637510	44.695304	354.50	1.538	o2	90	1.364
-84.637442	44.695386	354.28	1.067	o1	90	1.000
-84.637446	44.695423	354.29	1.933	o1	90	1.727
-84.637478	44.695490	354.79	1.233	o1	90	1.273
-84.637697	44.695521	354.80	0.867	o1	90	0.909
-84.637677	44.695360	355.26	1.154	o2	90	0.909

(Continued)

Table 6 (Concluded)						
Tree Base Location			Tree Model Data			
Longitude	Latitude	Elevation, m	Vertical Scale	Tree Model ID	Rotation, deg	Horizontal Scale
-84.637757	44.695392	355.04	1.077	o2	90	1.364
-84.637833	44.695498	354.54	1.000	o1	90	0.682
-84.637884	44.695510	354.54	0.769	o2	90	0.545
-84.637794	44.695769	354.57	2.133	o1	90	1.818
-84.637535	44.695272	354.48	0.850	p1	90	1.033
-84.637382	44.695248	353.92	1.050	p1	90	0.867
-84.637306	44.695220	353.56	1.100	p1	90	0.500
-84.637382	44.694934	353.66	1.275	p1	90	0.500
-84.637393	44.694915	353.67	1.275	p1	90	0.500
-84.637408	44.694875	353.66	1.325	p1	90	0.500
-84.637388	44.694890	353.65	1.275	p1	90	0.500

A total of seven geometric tree models were used to characterize the vegetation tree structure within the Grayling site (Table 7). Five of these models (forest oak.wes, forest pine.wes, valley oak1.wes, valley oak2.wes, and valley pine.wes) are the models used in Release 2.0. Two additional tree models (dead pine.wes and big oak.wes) were characterized after Grayling I and used to develop the information base for Release 4.0. The "stick figures" for the seven geometric models are provided in Figures 11a-g. The two additional tree models are described below.

Table 7 Three-Dimensional Tree Models		
Filename	Code	Description
forest_oak.wes	o3	Black oak tree model (9-m height)
forest_pine.wes	p2	Jack pine tree model (15.7-m height)
valley_oak1.wes	o1	Black oak tree model #1 (3.3-m height)
valley_oak2.wes	o2	Black oak tree model #2 (1.4-m height)
valley_pine.wes	p1	Jack pine model (4.6-m height)
big_oak.wes	bo	Multistem red oak tree model (9.5-m height)
dead_pine.wes	dp	Dead jack pine tree model (4.6-m height)

A small (4.6 m) jack pine (dead) tree geometric model was developed because of the presence of several dead trees in the valley area (Site E). An existing geometric model for the jack pine tree was modified by removal of third order branches from the p1 jack pine tree. No foliage was included on the jack pine tree.

A large (9.5-m) red oak tree geometric model was also developed. This model was a direct representation of the multiple stem oak tree in the valley area (Figure 9). Environmental characterization measurements and detail color photographs were used to generate the red oak model (for procedures, see Ballard (1994)). An example of this geometric model is shown in Figure 12. The red oak tree contained four main stems that emerged just above the tree base. A Lindenmayer system (L-system) (Prusinkiewicz and Hanan 1989) description of the geometric red oak tree model is provided in Table 8.

Foliage characteristics data were measured and consisted of leaf cluster lengths, average leaf lengths, and widths (Table 9). Also, data on the physical parameters of the forests were compiled for the thermal models. These data are included in Tables 10 and 11.

Graphic Displays of Grayling II (Release 4.0) Information Base

Throughout the entire information base development, high-resolution graphics were used by WES to verify development and placement of the 3-D tree models and for registration of the various data layers. The graphics were generated with a special software package utilizing the Grayling information base and selected viewports and fields-of-view.

Three-dimensional graphics allow one to "visualize" the structure of the 3-D site showing height of trees, branching structures, spacing of trees, location of roads, size and location of tree shadows, hilltop shadows, trees with and without leaves, and even color and density of leaves. However, sun position and local meteorological conditions control what parts of the 3-D scene that is in the direct path of the sun rays and the paths that are in shadow.

Figure 13 is a synthetic scene generated using the software package and the information base (Release 4.0) discussed in this report. The graphic shows the primary imaging area (Site E) from the viewpoint of the WES camera. The nonvegetated sandy area and tank trails are depicted as white areas. The multistem black oak tree is located in the center foreground. It is noteworthy that the black oak trees (shown as brown leaf colors) still contained their dead leaves. The leaves were still clinging to the trees on 15 April 1994 at the end of the exercise. Placed in the scene are four red fluorescent markers representing the boundary of the E-site, which is the main imaging area.

Table 8
L-Systems Description of Main Black Oak Tree in Imaging Area

```
/*
** @(#) big_oak.lsys 1.2 3/24/94 : USACE Waterways Experiment Station EN-C
*/

#define maxgen 150

START: '(0.3,0.2,0.1) !(30) F(10) \
       [ [ +(10) A(30,5,0)] [ /(-20) +(35) F(20) -(20) A(75,10,78.5) ] ] \
       /(175) [+(45) F(30) -(30) A(200,10,0)] \
       /(-85) [+(45) F(30) -(28) A(400,10,0)]


/*  p1: A -> If initial tilt angle isn't vertical: increase angle
           and continue.                              */

p1: A(ht,ang,rot): ((ht < 970) && ( ang > 0 )) \
              -> !(30.0 - 0.029 * ht) -(0.5) F(20) \
                 [ B(ht,rot) ] A(ht+20,ang-.5,rot+75)

/*  p1: A -> Tilt angle now vertical: stop angle increase    */

p1: A(ht,ang,rot): (ht < 970) \
              -> !(30.0 - 0.029 * ht)  F(20) \
                 [ B(ht,rot) ] A(ht+20,ang,rot+75)

/*  p2: B -> If branch height is greater than 4m then decrease
           angle and length                          */

p2: B(ht,rot): (ht > 400) \
         -> \(rot) !(5) +(85.0 - 0.05 * ht) X( 500.28 + -0.27 * ht,3 )

/*  p2: B -> If branch height is less than or equal to 4m increase
           branch angle and branch length                  */

p2: B(ht,rot): (ht <= 400 ) \
         -> \(rot) !(4) +(85.0 - 0.05 * ht) X( 100.28 + 0.75 * ht,3)


/*  p10: X -> Fork branches and provide variation in branch length
           and fork angles                           */

p10: X(len,w) ->(.25) F(len * .40 ) !(w) \(20) [ &(22) F(len * .60) ] \
                       [ /(22) F(len * .60) ]
          ->(.50) F(len * .40 ) !(w) [ &(22) F(len * .60) ] \
                       [ /(22) +(5) F(len * .30) ]
          ->(.25) F(len * .40 ) !(w) \(-25) [ &(22) F(len * .50) ] \
                       [ /(22) F(len * .60) ]
```

Table 9
Foliage Data

Tree Type	Average Length, cm	Average Width, cm	Comment
Black Oak	11	6	Leaf
Jack Pine	3	—	Needle
Red Oak	12	5	Leaf – None present during Grayling II

Table 10
Model Parameters for Deciduous Forest Canopies

Model Parameter	Top Layer	Middle Layer	Bottom Layer
Leaf frequency distribution factor	1	1	1
Leaf clumpiness factor	0.1	0.1	0.1
Leaf area index	3.4	0.8	0.4
Long-wave emissivity	0.98	0.98	0.98
Fractional shortwave absorption coefficient	0.089	0.042	0.040
Leaf stomatic resistance to water vapor diffusion	0.07	0.07	0.07

Table 11
Model Parameters for Coniferous Forest Canopies

Model Parameter	Top Layer	Middle Layer	Bottom Layer
Leaf frequency distribution factor	1	1	1
Leaf clumpiness factor	0.1	0.1	0.1
Leaf area index	1.5	5.3	1.0
Long-wave emissivity	0.98	0.98	0.98
Fractional shortwave absorption coefficient	0.389	0.019	0.028
Leaf stomatic resistance to water vapor diffusion	0.66	0.66	0.66

Figure 14 is a generated synthetic visual scene (perspective) at 1600 hr on a sunny day, looking in a northeasterly direction. Changes in the elevation topography and variability of the tree densities is clearly shown.

Figure 15 is a generated synthetic visual scene for 1600 hr on a sunny day, looking in a northward direction. Placed in the scene are three blue fluorescent markers used by the Airborne Seeker Evaluation Test System (ASETS) aircraft for infrared image rectification. The trees and their shadows in the valley area are visible.

It is noteworthy that the Grayling II high-resolution graphics presented and discussed above do not depict the snow cover or frozen ground conditions and, in many cases, the low visibility atmosphere conditions that occurred at Grayling during the winter-to-spring exercise (4 March - 15 April 1994).

3 Summary

This report documents the design, content, and development of the digital Grayling II environmental information base, Release 4.0, prepared for use as input to the SWOE thermal infrared scene generation procedure. The purpose of the information base is to provide spatial and tabular data required by the thermal models. To fulfill the requirements, the digital environmental information base was designed and developed for a 1.42- by 1.22-km site at Camp Grayling, MI. High-resolution graphics were generated showing the 3-D forested vegetation structure, foliage conditions, topography, and sandy (unpaved) roads that occupy the area.

References

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Hahn, C. (1994). "Grayling II site characterization and data summary," Technical Report prepared by the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, for the Smart Weapons Operability Enhancement Joint Test and Evaluation Program Office, Hanover, NH.

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Prusinkiewicz, P., and Hanan, J. (1989). "Lindenmayer systems, fractals, and plants." *Lecture notes in biomathematics*. Springer1-Verlag, New York.

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Smith, J. A., Ranson, K. J., Nguyen, D. (1981). "Thermal vegetation canopy model studies," Technical Report EL-81-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

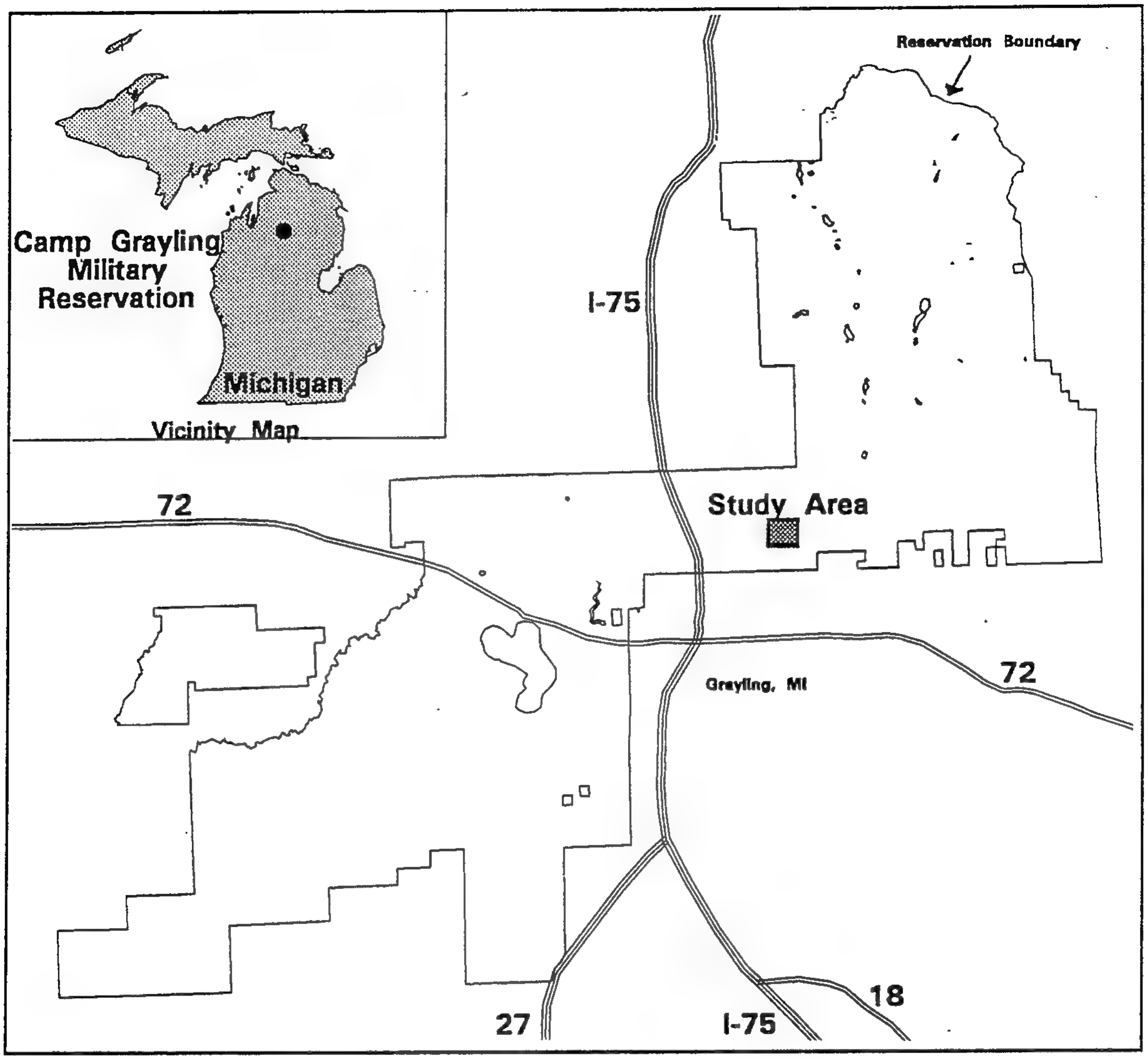

Figure 1. Grayling II environmental information base location map

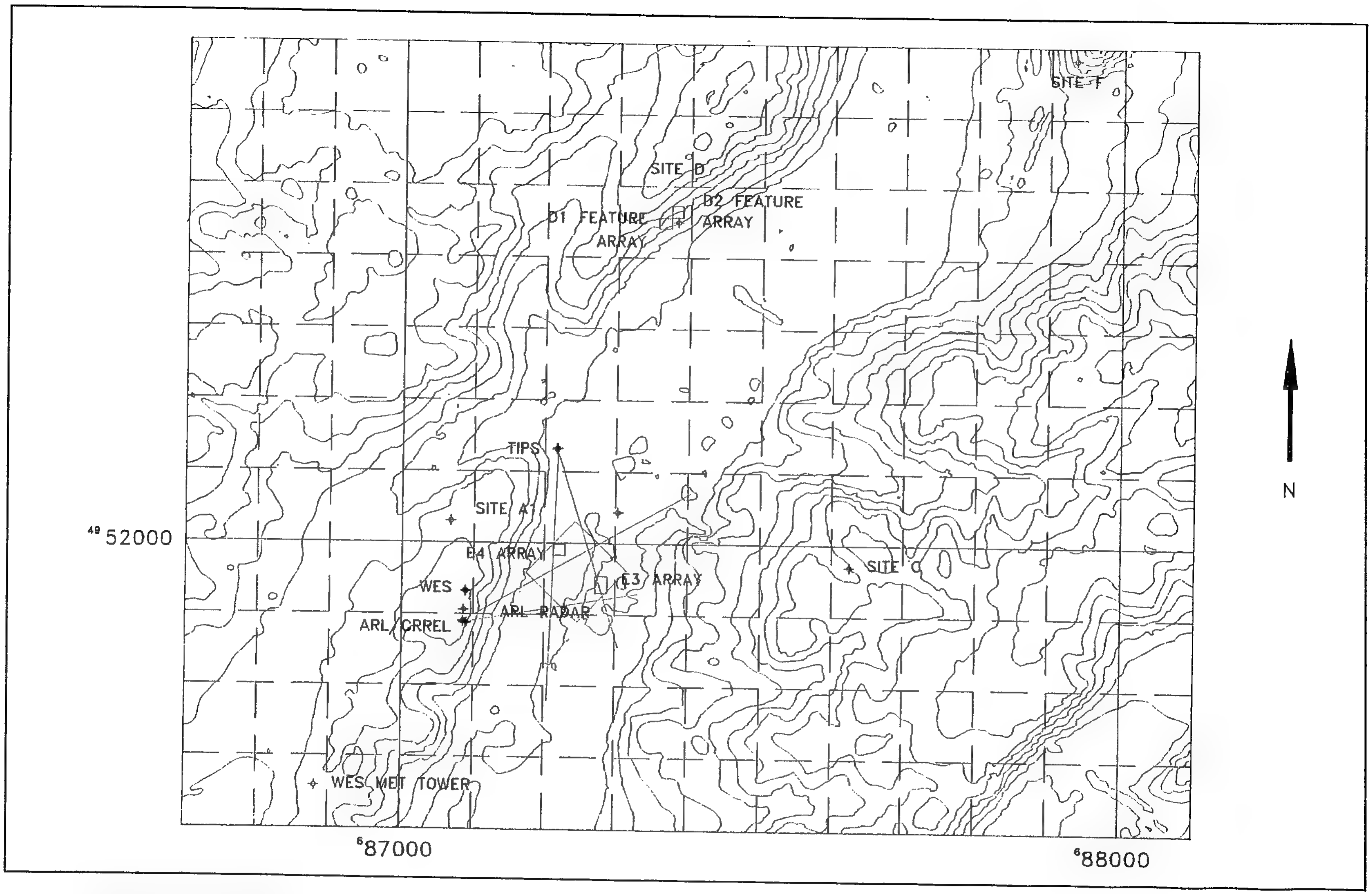

Figure 2. Grayling II environmental information base sensor and feature locations

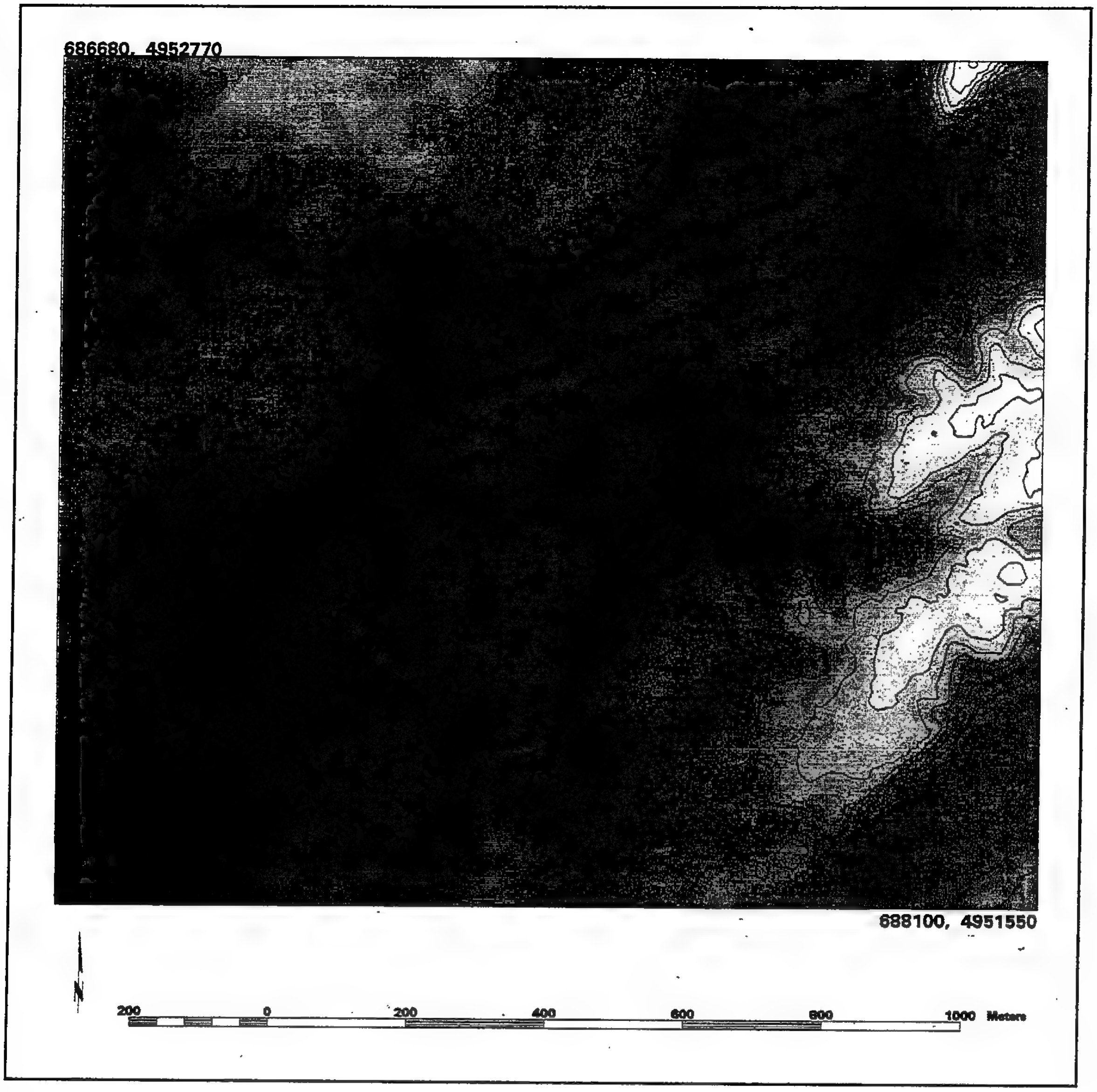

Figure 3. Elevation topography data of Grayling II information base. Contour lines are drawn at 2-m intervals

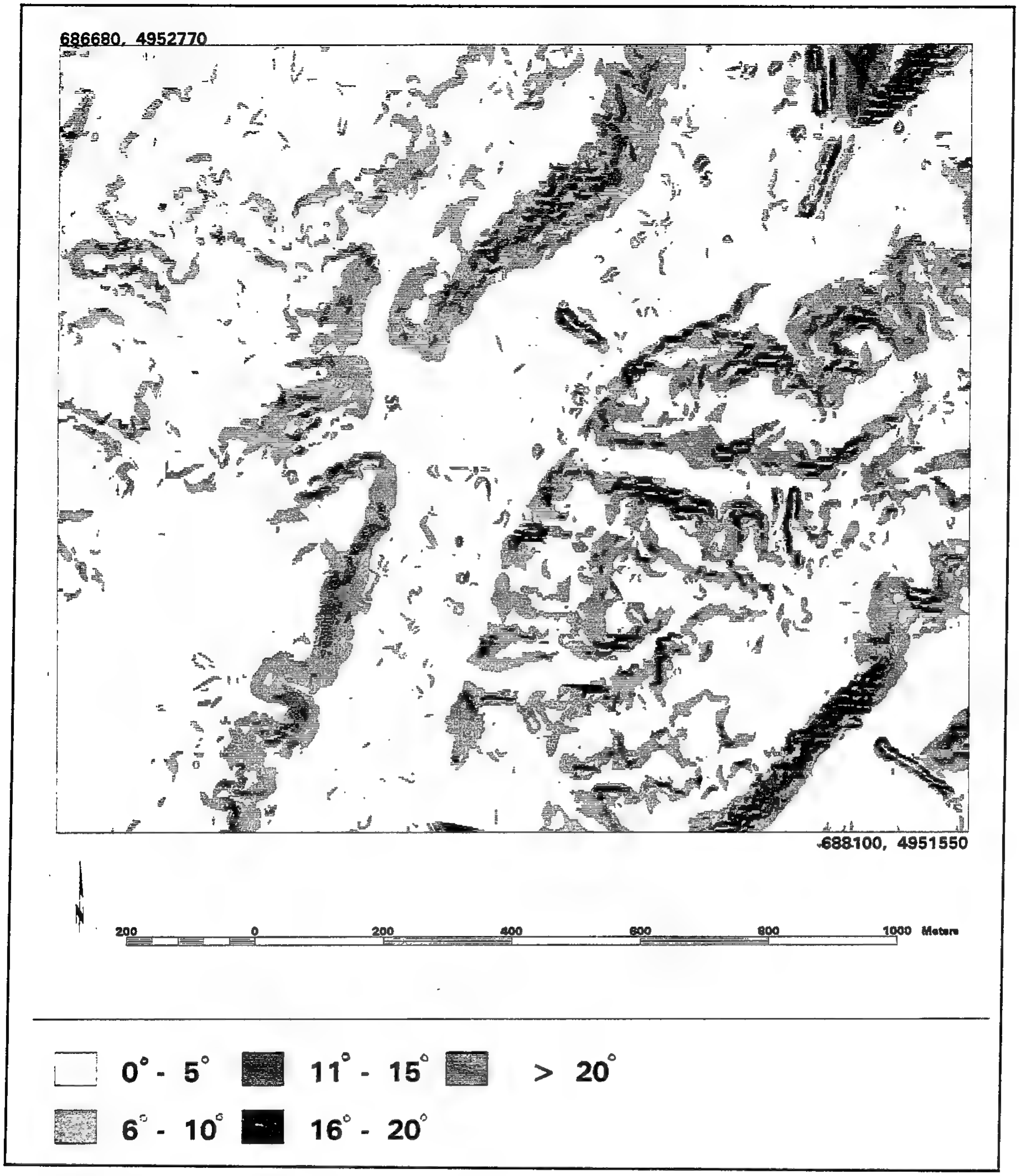

Figure 4. Slope magnitude data of Grayling II information base

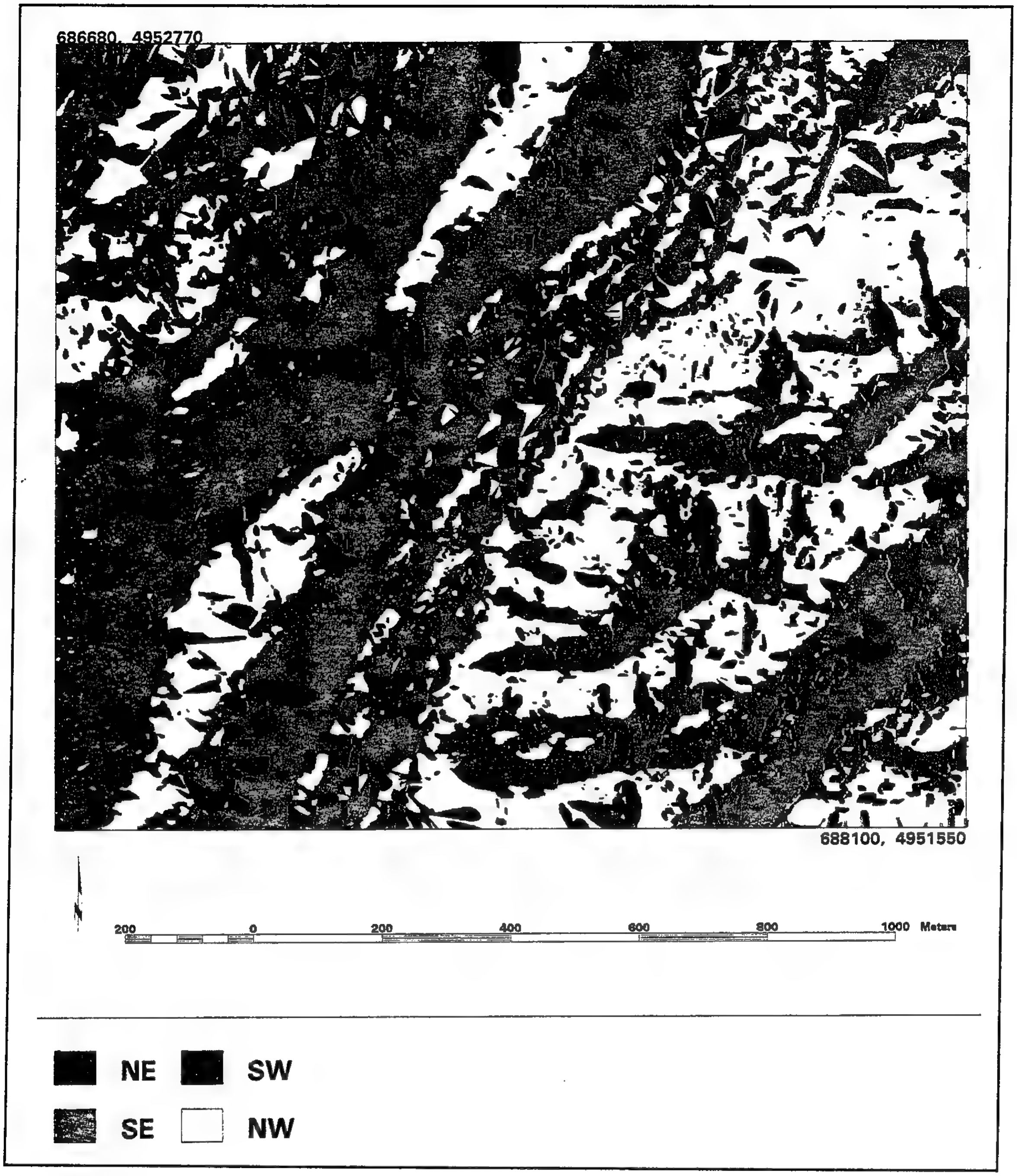

Figure 5. Slope aspect data of Grayling II information base

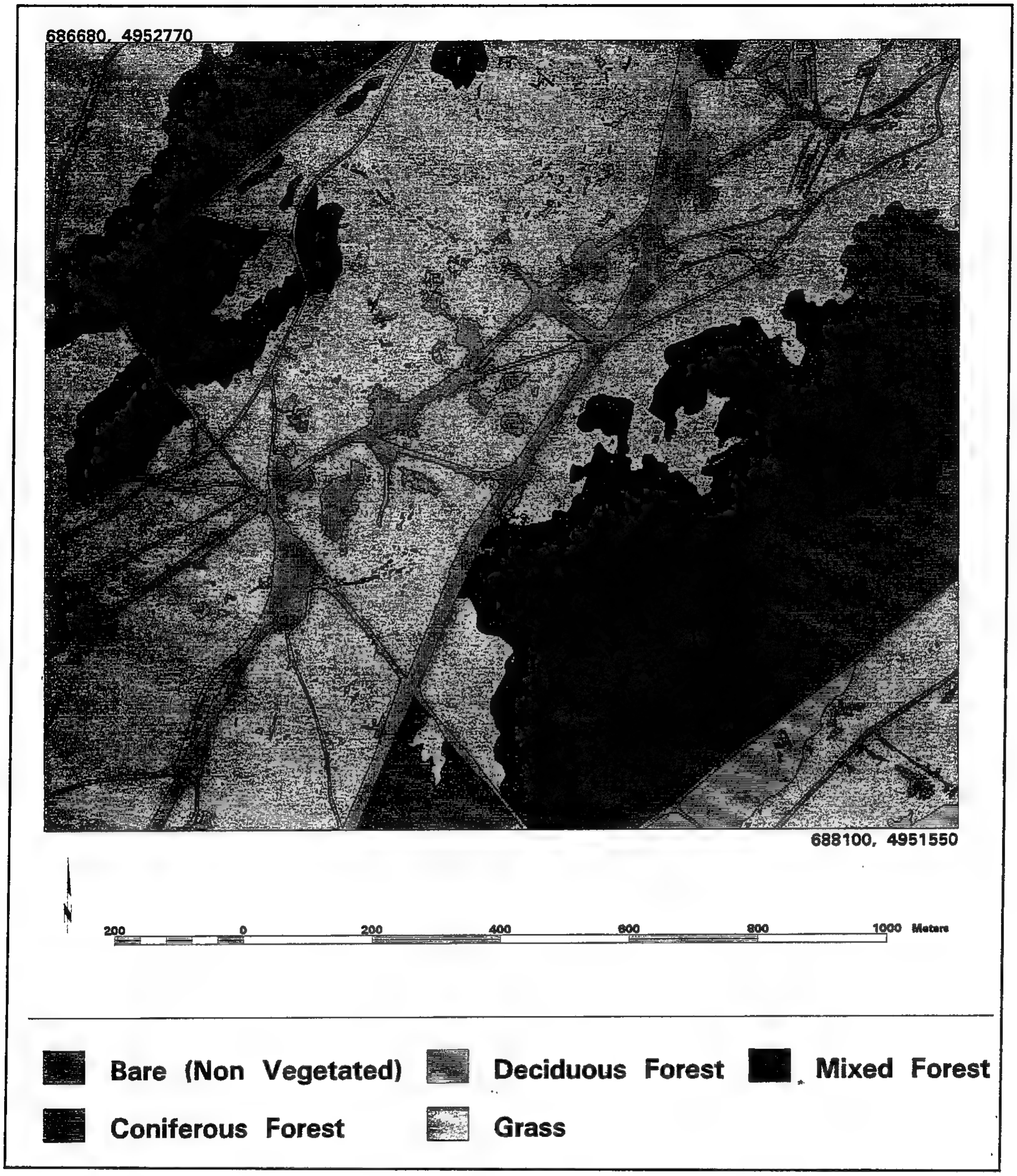

Figure 6. Vegetation type data of Grayling II information base

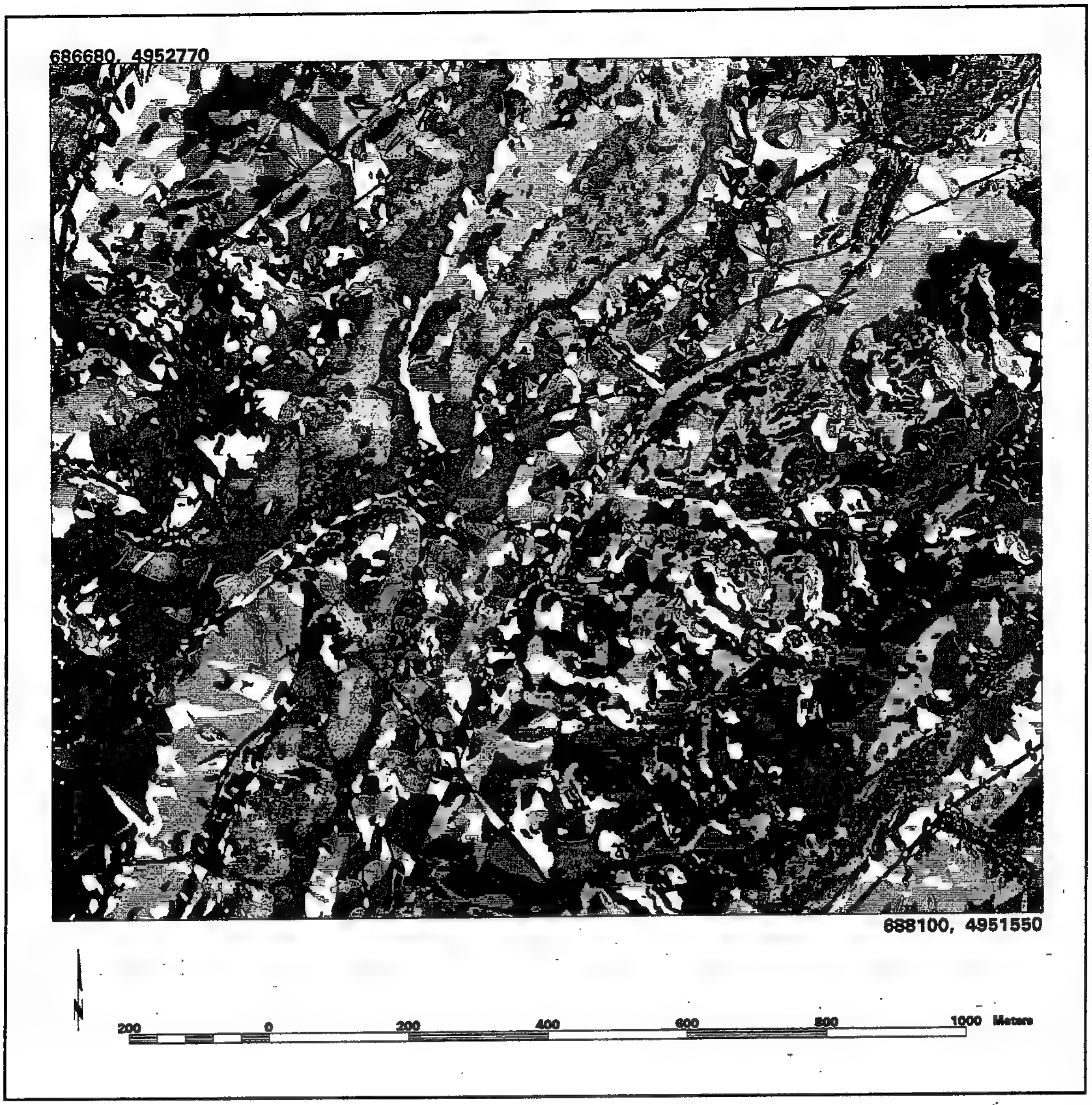

Figure 7. Landscape feature data of Grayling II information base. Map contains 100 features as depicted by different colors

Figure 8. Charge Couple Device imagery of ground imaging area with snow cover

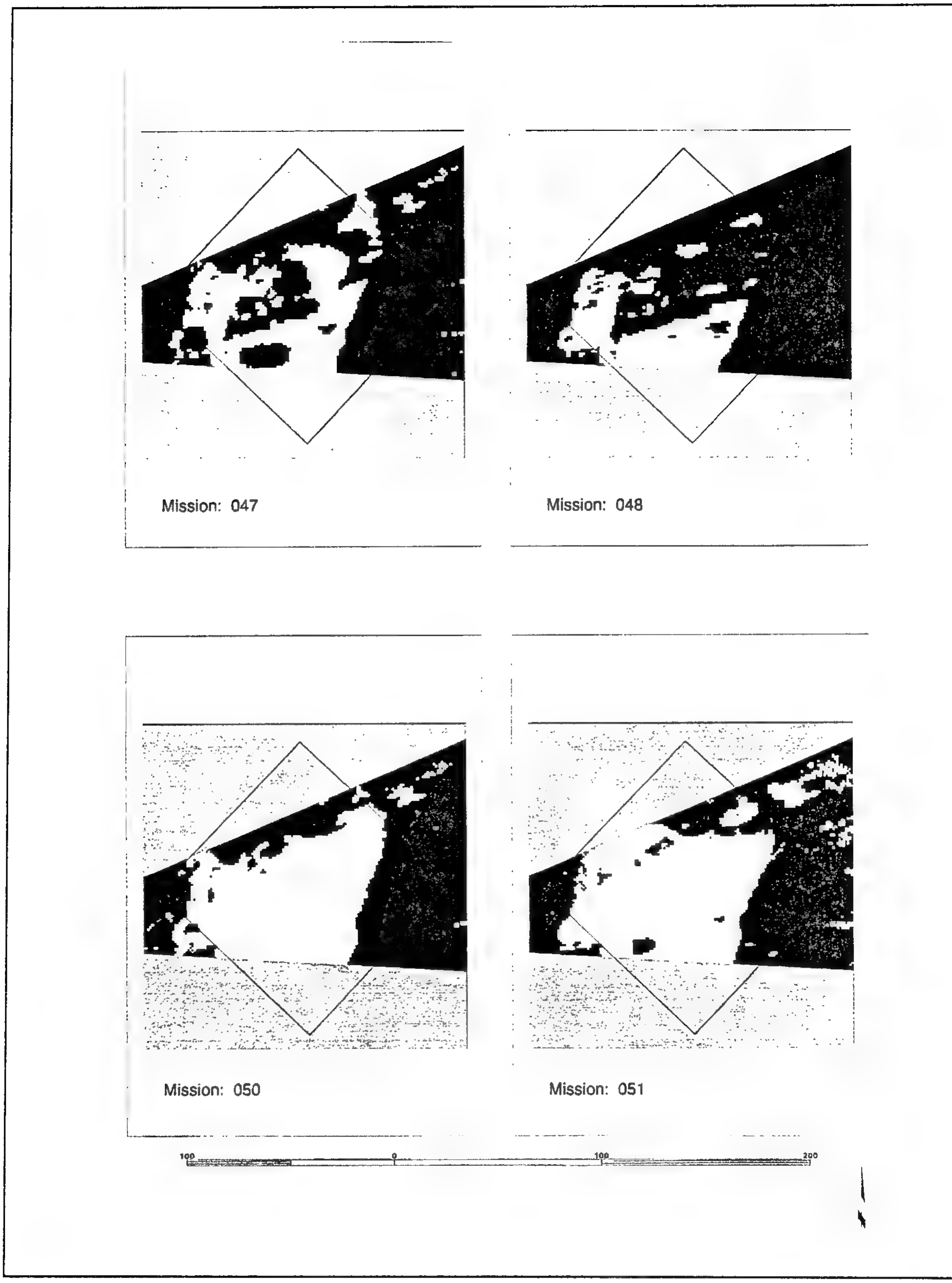

Figure 9. Snow cover map data of Grayling II information base. White and black regions represent snow cover and no snow cover, respectively. Gray region represents areas outside the field of view of CCD camera and were not mapped. Square outline represents corners and boundary of main imaging area (Site E) (Sheet 1 of 7)

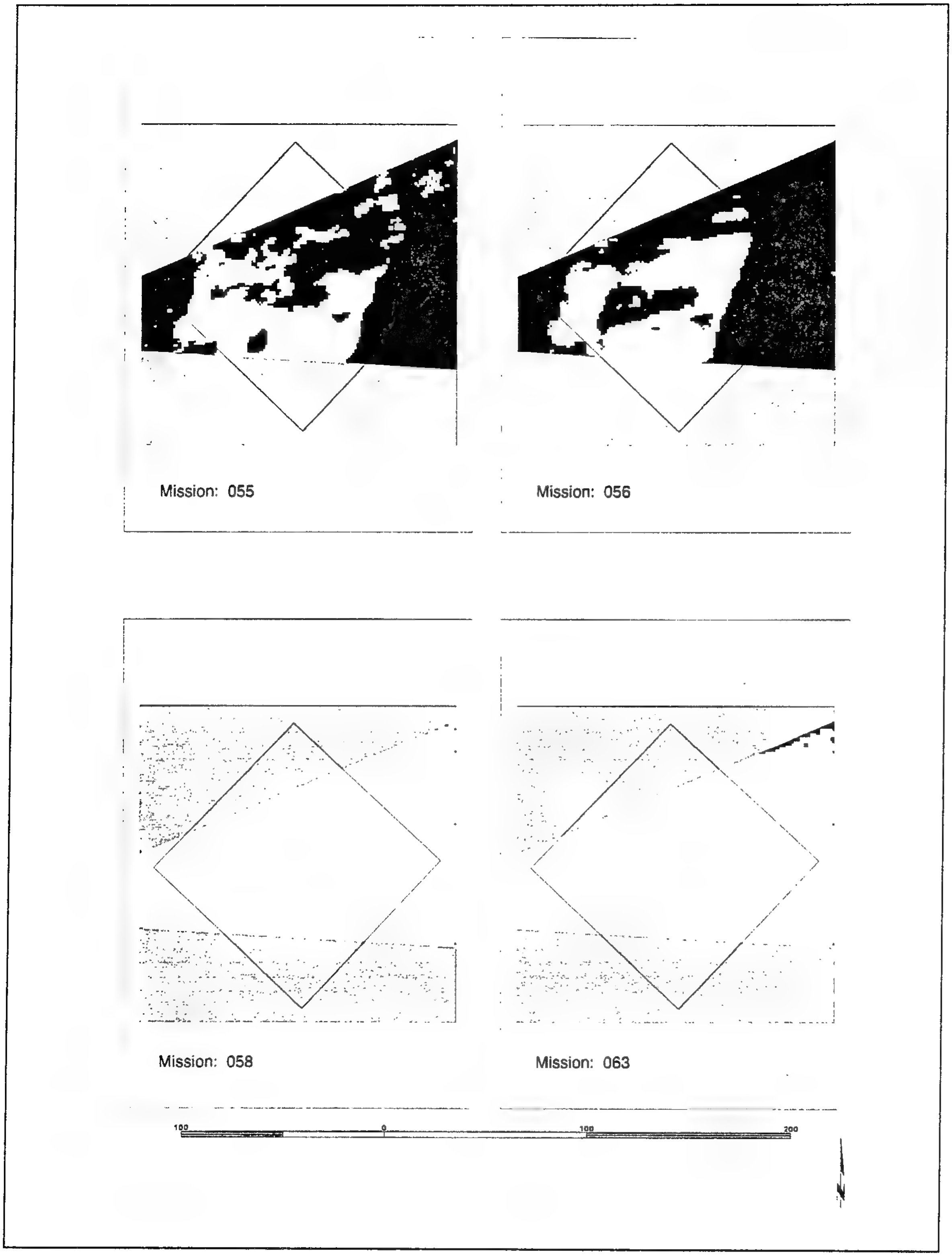

Figure 9. (Sheet 2 of 7)

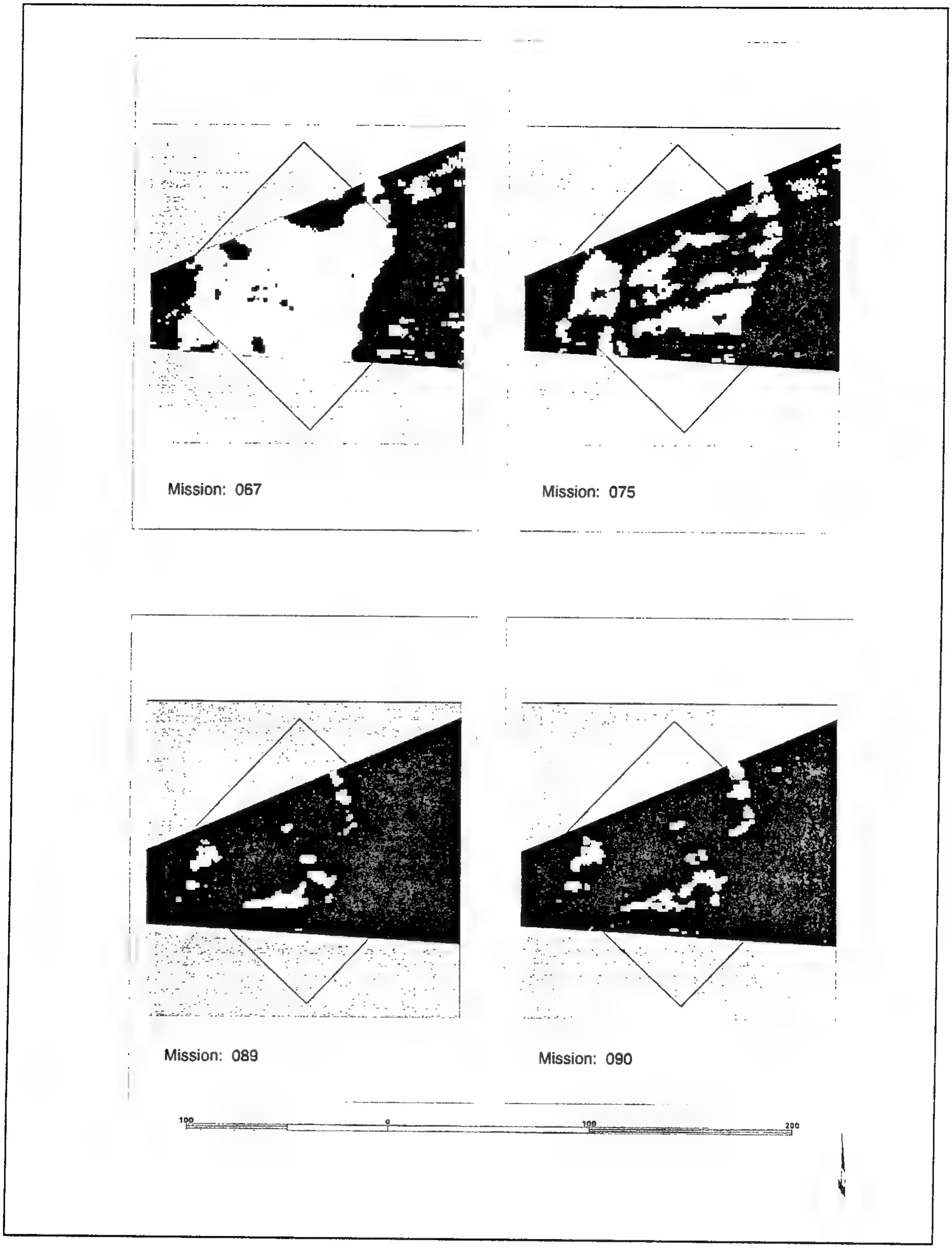

Figure 9. (Sheet 3 of 7)

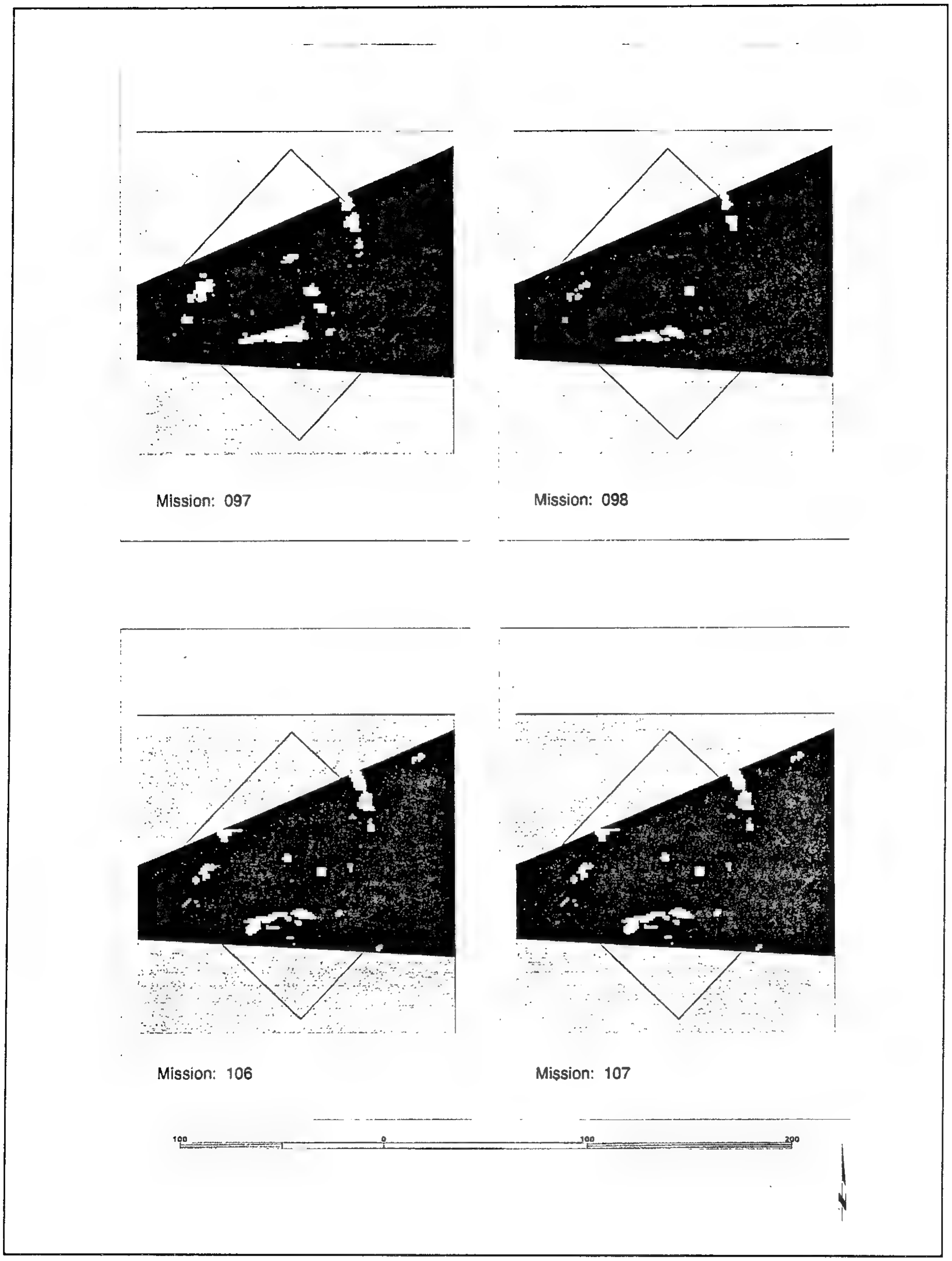

Figure 9. (Sheet 4 of 7)

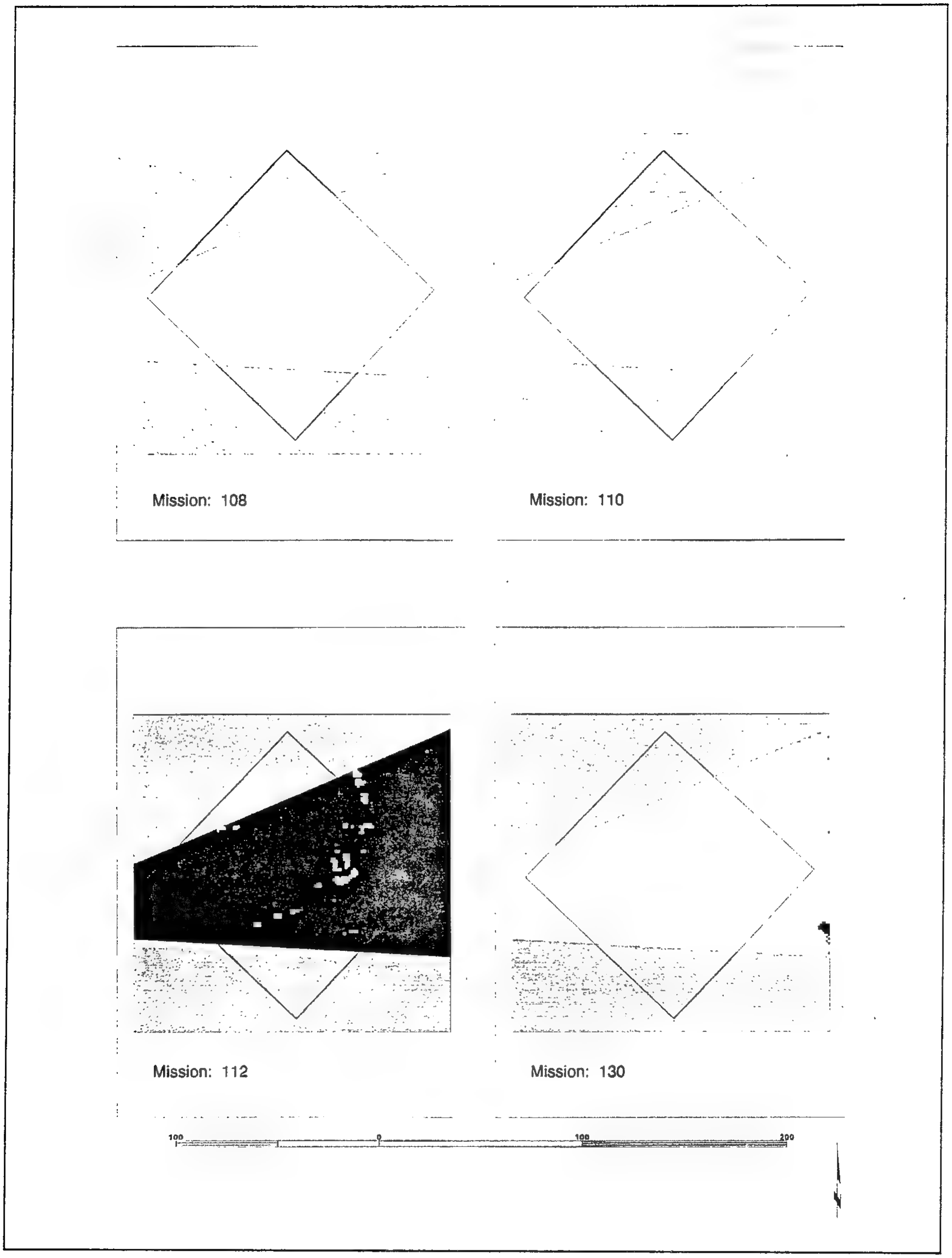

Figure 9. (Sheet 5 of 7)

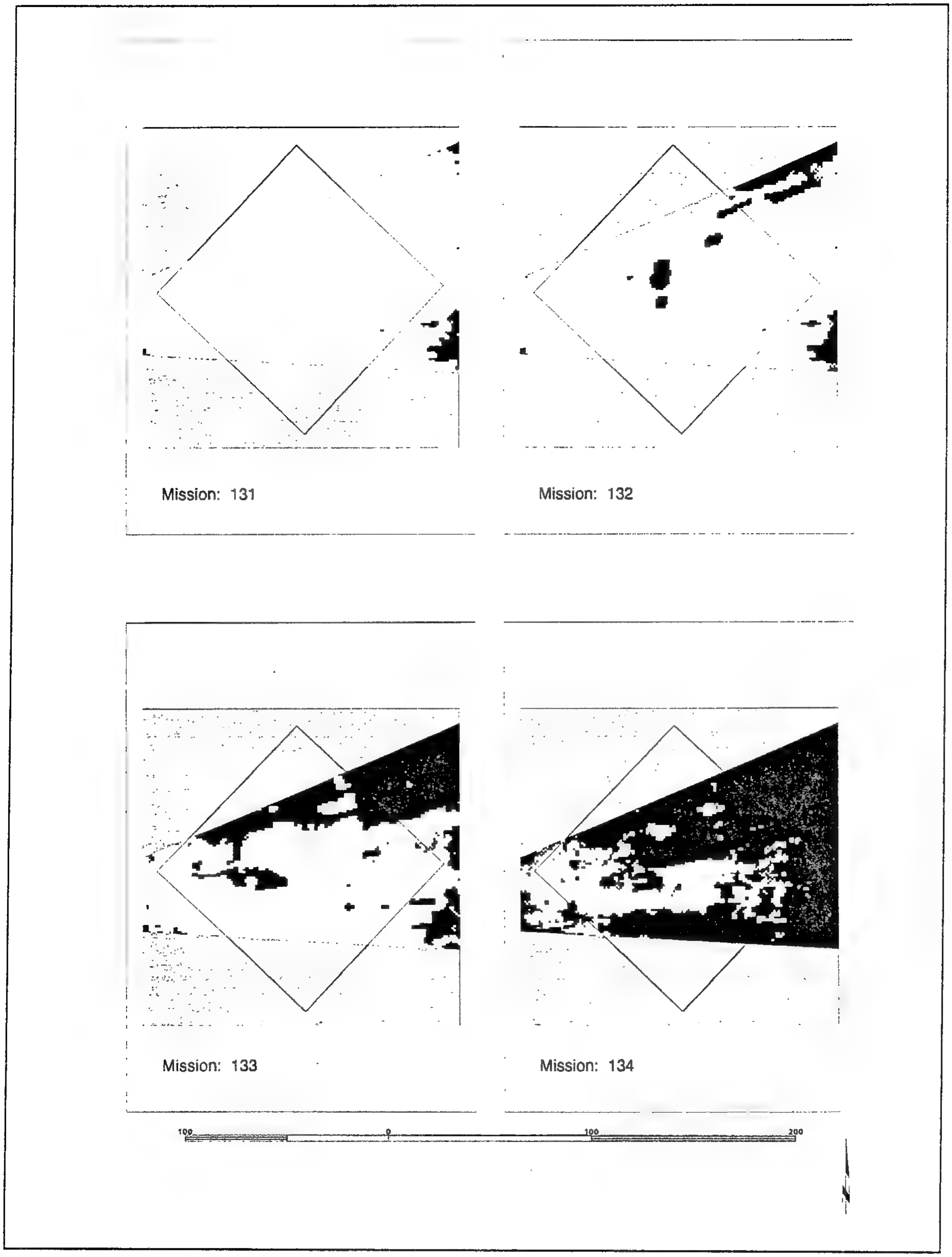

Figure 9. (Sheet 6 of 7)

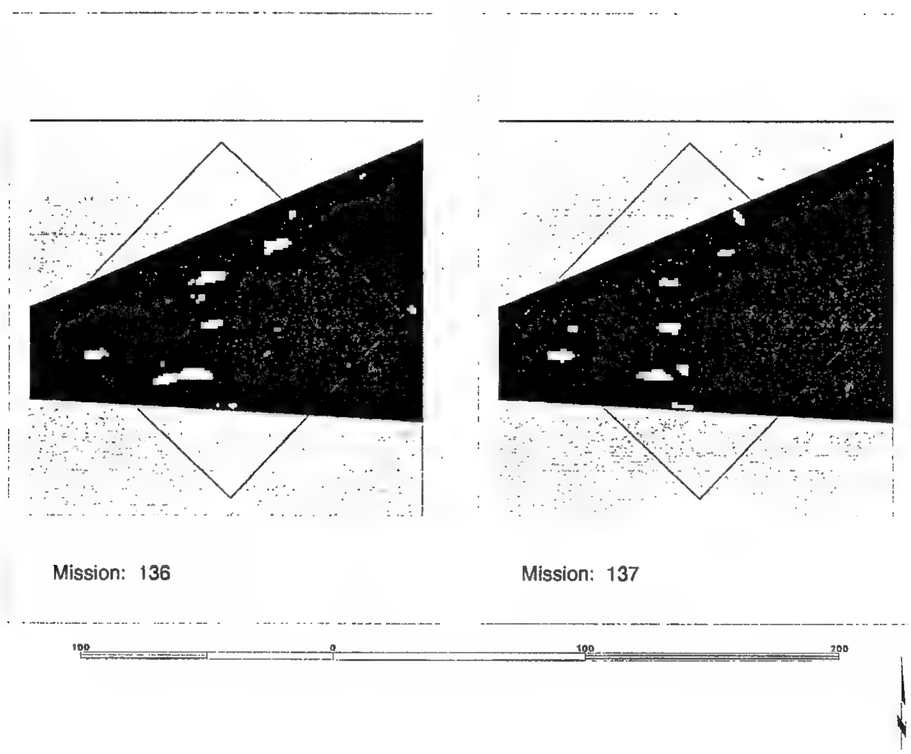

Figure 9. (Sheet 7 of 7)

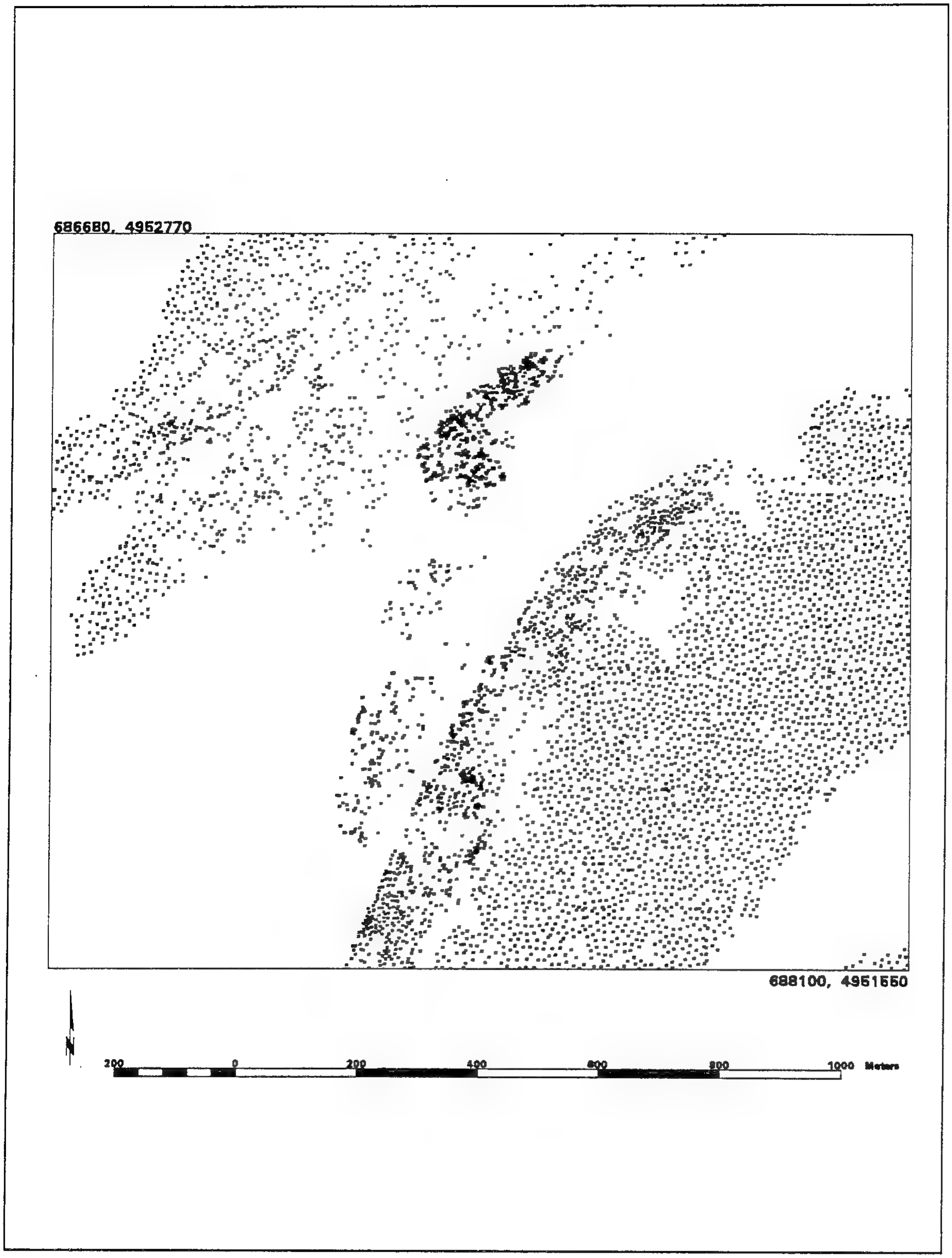

Figure 10. Tree basal location data of Grayling II information base

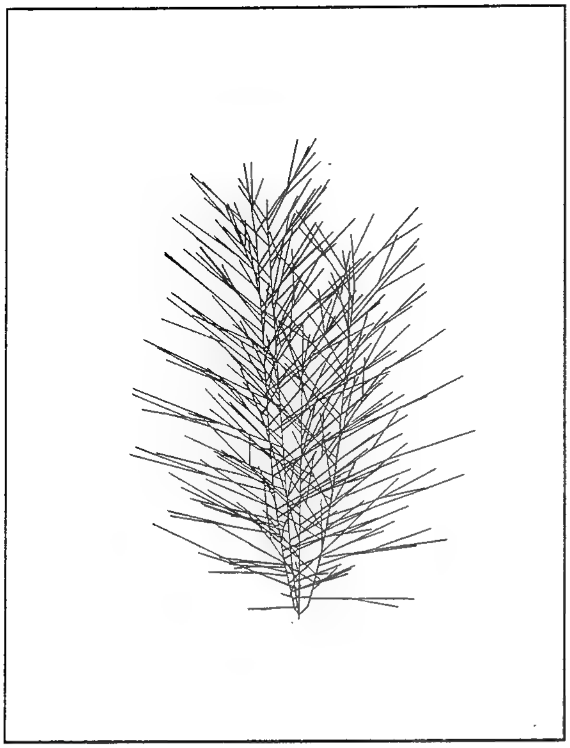

Figure 11a. Multistem red oak tree model (9.5-m height)

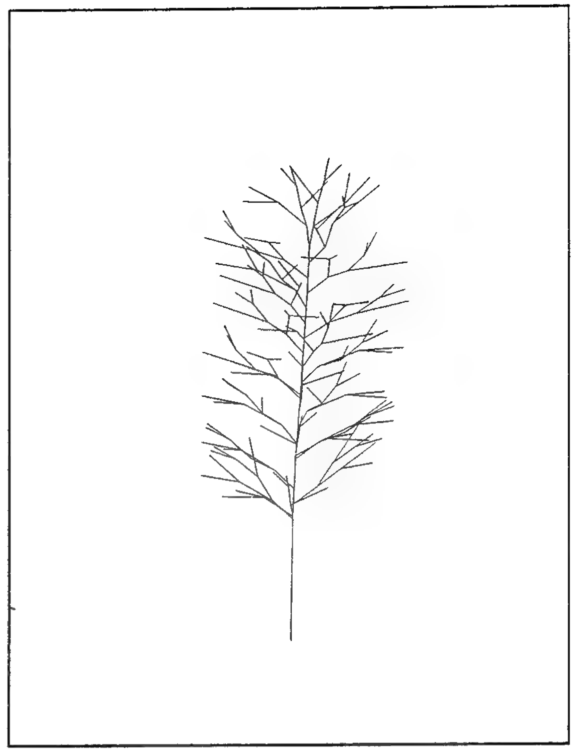

Figure 11b. Black oak forest tree model (9-m height)

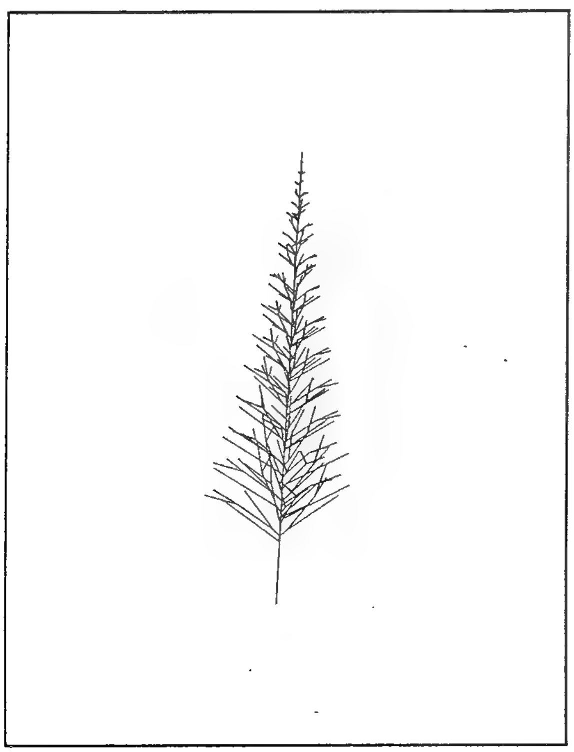

Figure 11c. Jack pine forest tree model (15.7-m height)

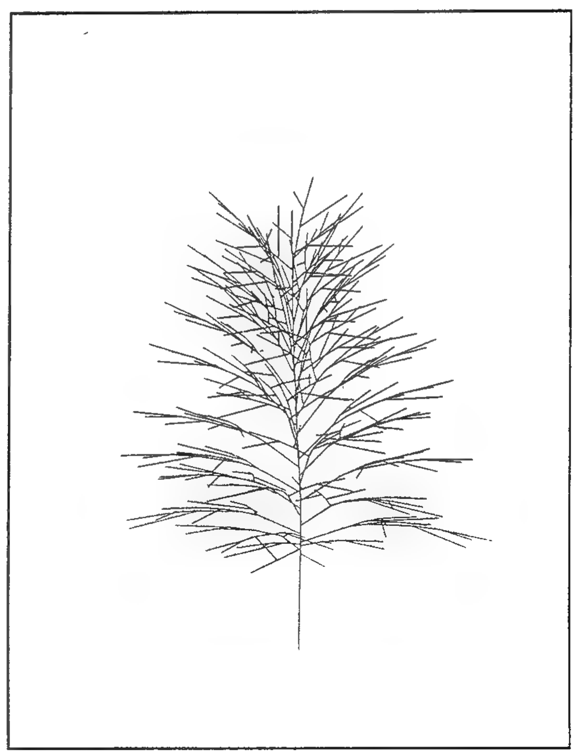

Figure 11d. Black oak valley tree model #1 (3.3-m height)

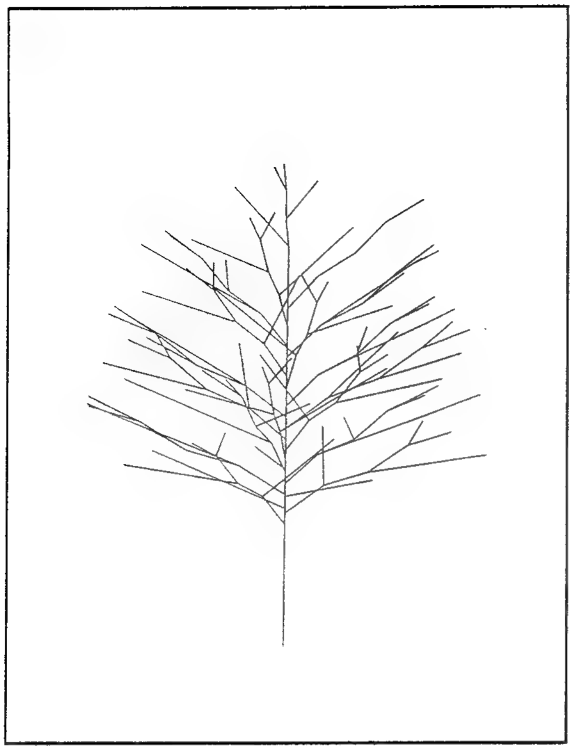

Figure 11e. Black oak valley tree model #2 (1.4-m height)

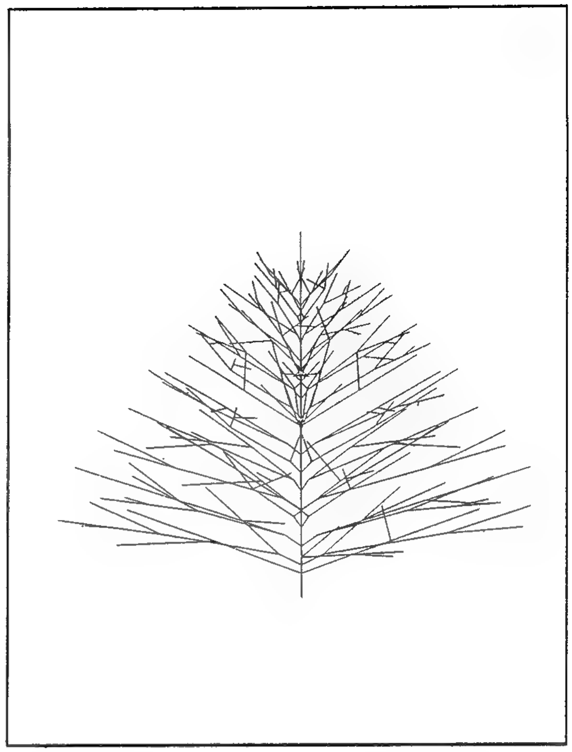

Figure 11f. Jack pine valley tree model (4.6-m height)

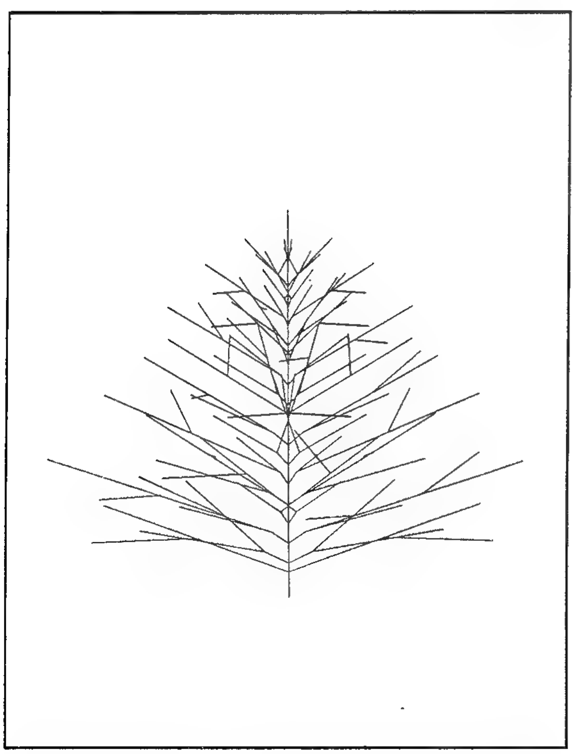

Figure 11g. Dead jack pine valley tree model (4.6-m height)

Figure 12. Large red oak tree in center of Site E during time of field survey

Figure 13. Generated synthetic visual scene for 1200 hr for sunny day using a field-of-view of 50 deg by 30 deg from WES camera position (HT = 30 m). View is looking east across the E-site showing synthetic trees, vehicle test track, and forested areas

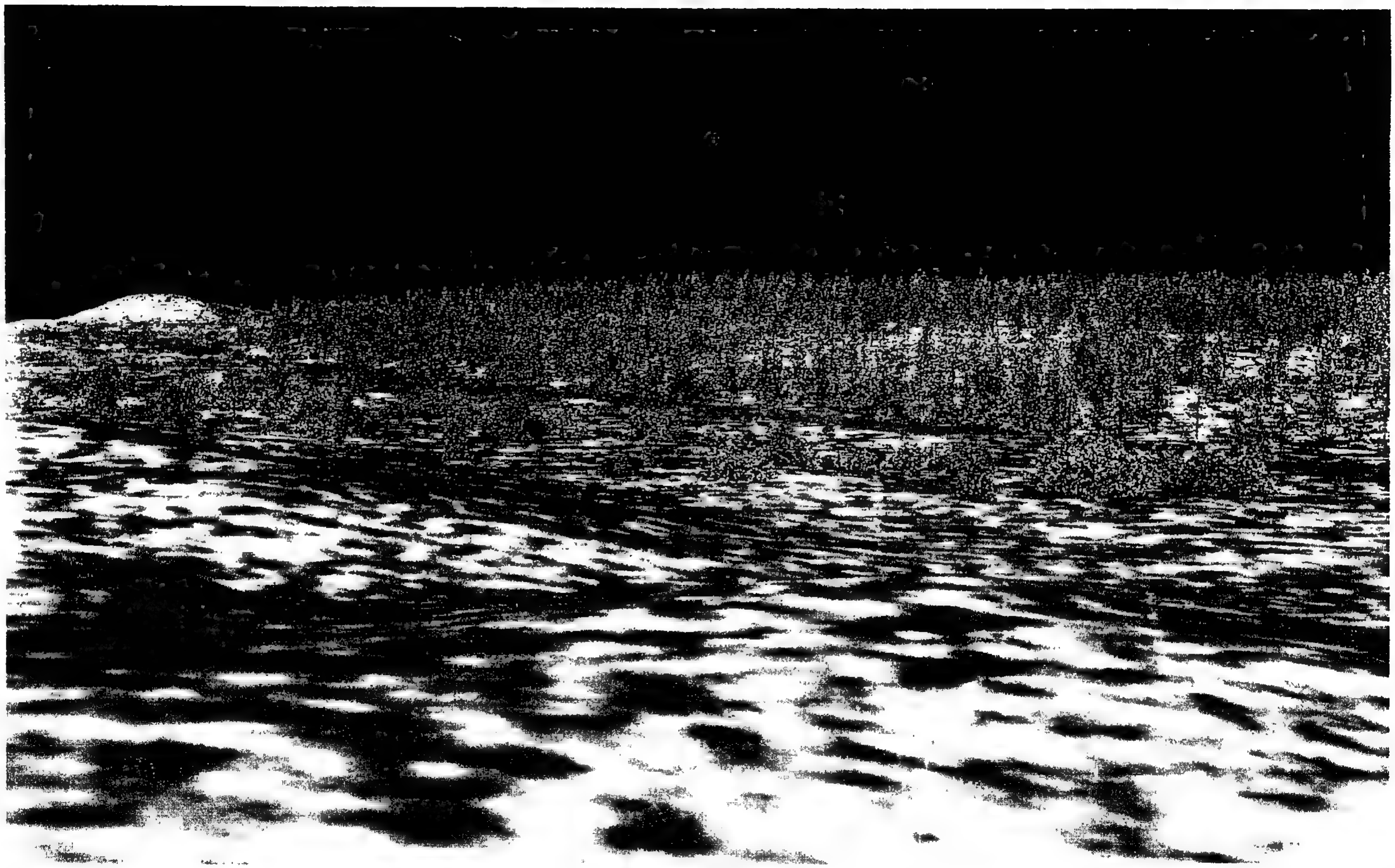

Figure 14. Synthetic visual scene for portion of Grayling II information base for 1600 hr on sunny day. Scene shows several features, including forested area and vehicle test track

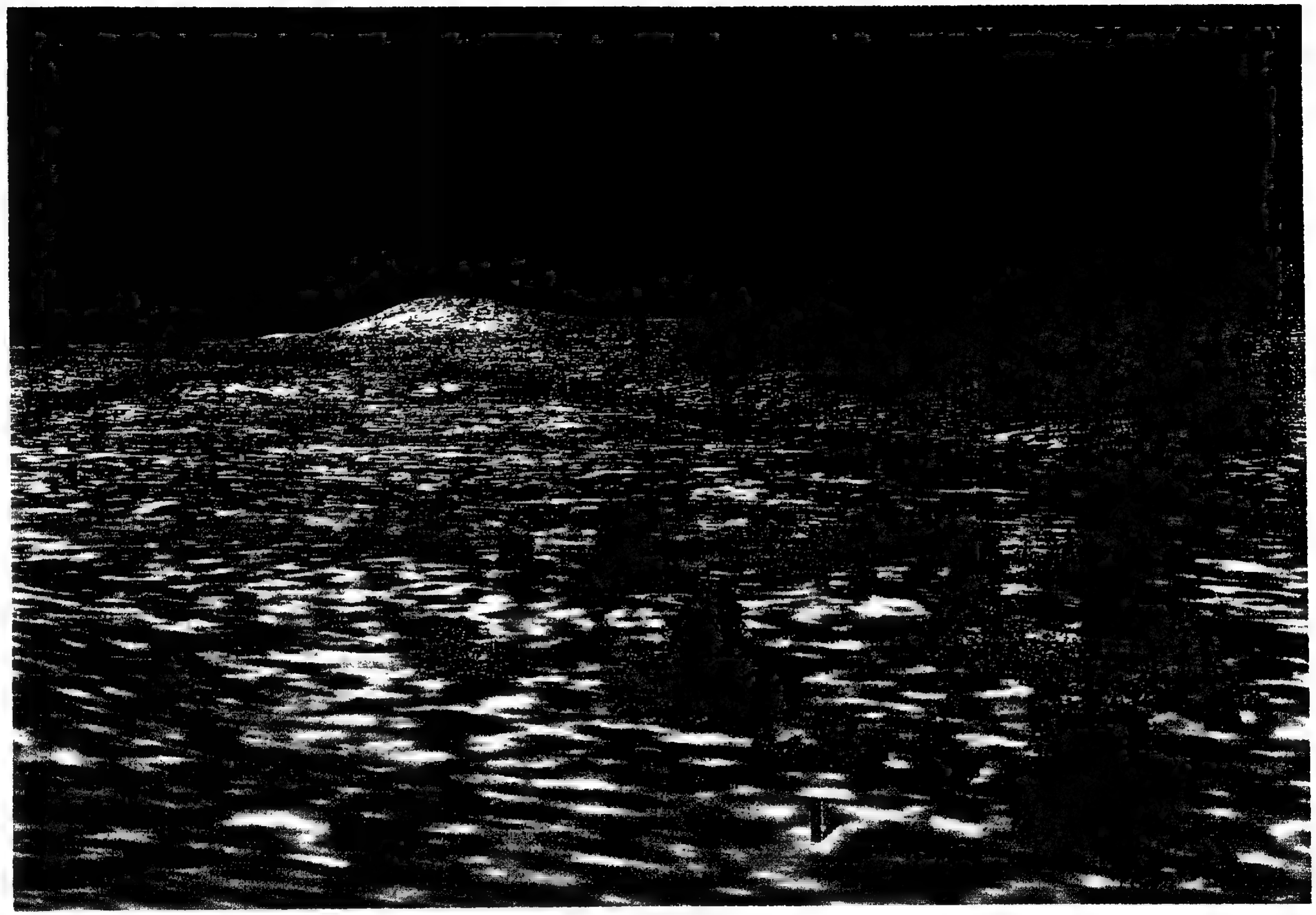

Figure 15. Synthetic visual scene for portion of Grayling II information base at 1600 hr on sunny day, looking in a northward direction. Scene shows coniferous forest on upper right, vehicle test track, hill, and individual coniferous and deciduous trees in valley area

Appendix A
Information Base File Formats

These are the format specifications for the digital data used in the Smart Weapons Operability Enhancement (SWOE) scene generation procedure for the Grayling II information base.

File Name	Format	Description
elevation.asc	ASCII raster format	Floating point elevation data for models
elevation.[dgf,hgf]	CIG binary General Grid File (GGF) format	Floating point elevation data for SWOE scene generation
fid.asc	ASCII raster format	Polygon feature ID raster layer
fidsmc.col	CIG binary color format	Two-layer feature ID and surface material code file used by SWOE scene generation
pfidp.inp	ASCII tabular format	Tabular index listing of polygon feature IDs and their associated surface material codes
usmc.inp	ASCII tabular format	Tabular index of surface material codes
<model_name> .wes	WES 3-D tree geometry ASCII format	An ASCII tabular listing of x,y,z, and diameters of the tree geometry
tree_loc.dat	ASCII tabular format	Geographic tree basal locations, tree models, and model scaling factor
*.met, *.sol	SWOE meterological format	Grayling II information base meterological data
daylist.dat	ASCII tabular format	Listing of all available days of meteorological data

Meteorological Data

The Grayling II information base contains two different files describing the meteorological conditions during the program: standard meteorological data and solar flux data. A text description of the standard meteorological data (*.met files) is as follows:

line 1: General Information

line 2: Altitude of Station (meters above MSL), Latitude Longitude, Time Flag

line 3: Time Step, Number of Steps, Year, Season Flag, Dry Soils Flag

line 4,5: Day, Time, Pressure, Temperature, Relative Humidity, Wind Speed, Wind Direction, Visibility, Aerosol Flag, Precipitation Amount, Precipitation Type, Low Cloud Amount, Low Cloud Type, Medium Cloud Amount, Medium Cloud Type, High Cloud Amount, High Cloud Type, Global Solar, Direct Solar, Diffuse Solar, IR Downwelling, Solar Zenith, Solar Azimuth

lines 6-n: Data Values

The following FORTRAN format statement describes the data values format:

FORMAT (2I3,I2,F7.1,3F6.1,F7.1,F5.1,I4,F7.2,I3,1X,3[F4.1,I2],4[7.1],F6.1,F7.1)

A text description of the solar flux data (*.sol files) is as follows:

line 1-24: Julian Day, Hour, Minute, Low Cloud Amount, Weighted Total Solar, Weighted Direct Solar, Weighted Diffuse Solar, Clear Sky Total Solar, Clear Sky Direct Solar, Clear Sky Diffuse Solar, Overcast Total Solar, Overcast Direct Solar, Overcast Diffuse Solar

The following FORTRAN format statement describes the data values format:

FORMAT (I3,I2,I2,F3.1,9[F6.1])

Texture Data

Texture for the Grayling II environmental information base consists of a single textural attribute table. Each row in the table contains the image mission number, wavelength, date/time, standard deviation of radiance in watts/ster-radian*meter^2, correlation length in meters, correlation length in image pixels, pixel resolution in meters, and surface description of the texture.

Terrain Data ASCII raster

The ASCII format for terrain data layers consists of two parts: (a) header section and (b) data section. The header section is composed of free formatted 15 lines of ASCII text that describes the geographic region of the data layer. Below is an example:

```
CAMP GRAYLING MI FOR SWOE/JT&E
NORTH-SOUTH RESOLUTION: 1.0
EAST-WEST RESOLUTION: 1.0
CENTER OF DATA (UTM): 687390.0 E   4952160.O W
CENTER OF DATA (LAT-LON):  44.698323N 84.634802W
ZONE:               16
NORTH:         4952770.00
SOUTH:         4951550.00
EAST:           688100.00
WEST:           686680.00
NSRES:               1.00
EWRES:               1.00
ROWS:             1220
COLS:             1420
```

The first line of the header section is text describing the title/region of the data layer. The second and third lines indicate the resolution of the data in meters. Lines 4 and 5 provide the center of the data set in Latitude/ Longitude and universal transverse Mercator (UTM) coordinates. Line 6 indicates the UTM zone of the data layer, and lines 7-12 describe the UTM boundaries and resolution of the data layer. Lines 13 and 14 specify the number of rows and number of columns in the data layer. Line 15 is left blank.

The data section is actual data values of the data layer; these data values can be either floating point values or integer. The data are in row-major order where data values run from west to east. The row data are arranged in order from north to south with each row ending in a carriage return (ASCII CR). Each data value within a row is separated by a blank space. Below is an example of a data section for two rows and four columns.

```
370.9 371.2 371.1 373.2
371.1 371.9 370.8 372.9
```

CIG Binary General Grid File (GGF)

The GGF format data are Latitude/Longitude floating point values with a 320-byte header section describing the location and size of the data file.

CIG Binary Color File

The CIG binary color format data are three-layer Latitude/Longitude integer values with a 512-byte header section describing the location and size of the data file. Typically, the first layer contains polygon feature IDs (FID) data; the second layer contains surface material code (SMC) data; and the third layer is left empty.

Appendix B
Physical Properties[1]

Coniferous Forest Canopy

Average Needle optical properties	
Reflectance	0.250
Transmittance	0.224
Average soil reflectance:	0.143
Global irradiance fraction:	1.0
Diffuse irradiance fraction:	0.18
Stomatal resistance:	0.22 min/cm

Number of layers:	3
Layer 1 (top)	
Leaf angle distribution:	Spherical
Leaf Angle Index:	0.80
Canopy density parameter:	0.10
Layer 2	
Leaf angle distribution:	Spherical
Leaf Angle Index:	1.0
Canopy density parameter:	0.10
Layer 3	
Leaf angle distribution:	Spherical
Leaf Angle Index:	0.20
Canopy density parameter:	0.10

Computed shortwave absorption coefficients:

Layer 1:	0.228
Layer 2:	0.214
Layer 3:	0.079
Soil:	0.306

1 Data values from Smith, Ranson, and Nguyen (1981). Please see References at end of main text.

Long-wave emissivity/absorption coefficients:

Layer 1:	0.98
Layer 2:	0.98
Layer 3:	0.98
Soil:	xxx

Deciduous Forest Canopy

Average Leaf optical properties

Reflectance	0.250
Transmittance	0.224
Average soil reflectance:	0.143
Global irradiance fraction:	1.0
Diffuse irradiance fraction:	0.18
Long-wave emissivity:	0.98
Stomatal resistance:	0.07 min/cm

Number of layers:	3
Layer 1 (top)	
Leaf angle distribution:	Spherical
Leaf Area Index:	0.80
Canopy density parameter:	0.10
Layer 2	
Leaf angle distribution:	Spherical
Leaf Area Index:	0.15
Canopy density parameter:	0.10
Layer 3	
Leaf angle distribution:	Spherical
Leaf Area Index:	0.05
Canopy density parameter:	0.10

Computed shortwave absorption coefficients:

Layer 1:	0.255
Layer 2:	0.046
Layer 3:	0.038
Soil:	0.486

Long-wave emissivity/absorption coefficients:

Layer 1:	0.98
Layer 2:	0.98
Layer 3:	0.98
Soil:	xxx